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(57) Abstract

An electrochemical power generating system includes a metal-air cell for a metal-air cell battery. The cell comprises a flexible, collapsible pouch having first and second opposed walls. At least one of the walls includes an air-permeable and electrolyte-impermeable air cathode. The cell further comprises a metal anode within the pouch and surrounded thereby having a first reaction face opposing the cathode, a spacer between the cathode and the reaction face of the anode for preventing the anode from contacting the cathode, and electrolyte intake and discharge ports for the pouch for passage of electrolyte through the pouch and between the anode and cathode.

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ELECTROCHEMICAL POWER GENERATING SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to metal-air cells and, more particularly, to electrochemical power generating systems using metal-air cells.

Metal-air cell batteries generally have several serially connected metal-air cells. Each cell has an anode made of a reactive metal such as aluminum or magnesium and an air cathode spaced from the anode. A suitable electrolyte, such as an aqueous solution of KOH, NaOH or NaCl, electrochemically couples the anodes and cathodes to produce an electrical potential and supply current to an electrical load. During the electrochemical reaction, the anodes are consumed. When the anodes are consumed, the battery must be refueled with new anodes and fresh electrolyte. Such refueling generally requires draining of spent electrolyte from the battery, adding new metal anodes one-by-one, and replenishing the electrolyte. The refueling operation in prior art metal-air batteries is time consuming and usually results in the machine or device powered by the battery being inoperative for an extended period during refueling.

Another problem with prior metal-air cell batteries is that during anode consumption the distance between the anode and cathode increases causing a decrease in voltage, power output, and efficiency of the battery.

Another problem is degradation of the electrolyte solution. As the reaction in the cell proceeds, reaction products build up in the electrolyte solution, and

concentration of the electrolyte increases, both of which cause a decrease in performance of the cell.

Another problem with prior metal-air cell batteries is the length of time it takes for the battery to become fully operational, i.e., to deliver full power. The temperature of the electrolyte circulating through the battery must be relatively high (e.g., 150°F) before the battery can fully energize the load. A metal-air cell cannot deliver much power at low temperatures and, consequently cannot generate much heat. Thus, if the electrolyte is initially cold, it typically takes several minutes to heat the circulating electrolyte to a sufficient operating temperature. Such a warm-up time is often a nuisance to the user and renders such metal-air cell batteries impractical for many applications. Moreover, when the cell is disconnected from its electrical load, the anode continues to be consumed at a low rate and thereby reduces the operating life of the cell.

SUMMARY OF THE INVENTION

Among the objects of the present invention may be noted the provision of improved metal-air cells and electrochemical power generating system which overcomes disadvantages and deficiencies associated with prior art cells and systems; the provision of such a generating system which maintains a substantially constant distance between the anode and cathode during consumption of the anode; the provision of such metal-air cells and power generating system which can be quickly and easily refueled when the anodes are depleted or consumed; the provision of such a

power generating system which more rapidly delivers full power; and the provision of such a generating system which discontinues or reduces anode consumption when the metal-air cells are disconnected from its electrical load.

Generally, an electrochemical power generating system of the present invention includes a metal-air cell for a metal-air cell battery. The cell comprises a flexible, collapsible pouch having first and second opposed walls. At least one of the walls includes an air-permeable and electrolyte-impermeable air cathode. The cell further comprises a metal anode within the pouch and surrounded thereby having a first reaction face opposing the cathode, a spacer between the cathode and the reaction face of the anode for preventing the anode from contacting the cathode, and electrolyte intake and discharge ports for the pouch for passage of electrolyte through the pouch and between the anode and cathode.

In another aspect of the present invention, a metal-air cell battery has a row or stack of collapsible metal-air cells arranged in face-to-face relationship and electrically interconnected. Each cell includes a flexible, collapsible pouch, a metal anode within the pouch and having a reaction face, and an air cathode having an outer face and an inner face with the inner face opposing the reaction face. A spacer is positioned between the inner face of the cathode and the reaction face of the anode for preventing the anode from contacting the inner face of the cathode. The cell also includes an electrolyte intake port and an electrolyte discharge port for passage of electrolyte through the casing and between the anode and cathode. The battery further comprises apparatus for urging opposite ends

of the row of collapsible cells toward each other thereby to urge the anode and cathode of each cell toward each other so that the distance between the inner face of the cathode and the reaction face of the anode of each cell remains generally constant during consumption of the anode.

In still another aspect of the present invention, an electrochemical power generating system has a first portion, including an electrolyte pump and electronic controls for controlling operation of the pump, and a separable second portion. The second portion comprises a row of metal-air cells electrically interconnected together. Each cell includes a casing, a metal anode within the casing and having a reaction face, and an air cathode having an outer face and an inner face with the inner face opposing the reaction face. A spacer is positioned between the inner face of the cathode and the reaction face of the anode for preventing the anode from contacting the cathode. The casing is provided with an electrolyte intake port and an electrolyte discharge port for passage of electrolyte through the casing and between the anode and cathode. A manifold having an intake port and a plurality of discharge ports is in fluid communication with the electrolyte intake ports of the cells so that electrolyte flowing through the manifold is directed through the intake ports of the cells. The second portion also includes an electrolyte reservoir and a mechanism for operatively connecting the discharge ports of the cells with the reservoir so that electrolyte discharged from the cells flows to the reservoir. The electrolyte reservoir and intake port of the manifold is operatively connectable with the electrolyte pump for fluid communication therewith so that the pump is able to draw

electrolyte from the reservoir and force it into the manifold. The second portion is releasably attachable to the first portion so that the second portion can be quickly attached to and detached from the first portion.

In yet another aspect of the present invention, an electrochemical power generating system comprises at least one metal-air cell, an electrolyte reservoir, and electrolyte transport apparatus for drawing electrolyte from the reservoir and moving it through the cell. A first sensor senses an operating condition of the power generating system. The system also includes a controller for selectively energizing the electrolyte transport apparatus as a function of the sensed operating condition whereby energizing the electrolyte transport apparatus causes electrolyte to be drawn from the reservoir and transported to the cell.

In yet another aspect of the present invention, an electrochemical power generating system comprises a battery having at least one metal-air cell including a casing, a metal anode within the casing and having a reaction face, and an air cathode having an outer face and an inner face with the inner face opposing the reaction face. The system further comprises apparatus for applying a bias voltage to the battery during periods when the battery is not supplying current to a load thereby to inhibit anode depletion. The voltage is of like polarity and of a potential at least equal to that of the battery.

In yet another aspect of the present invention, an electrochemical power generating system for supplying power to an electrical load comprises a primary battery. The battery has at least one metal-air cell including a casing,

an anode within the casing and having a reaction face, an air cathode having an outer face and an inner face with the inner face opposing the reaction face, an electrolyte intake port in the casing for passage of electrolyte through the casing and between the anode and cathode, and an electrolyte discharge port in the casing. The power generating system further includes apparatus for heating electrolyte within the battery when the temperature of the electrolyte is below a predetermined temperature.

Other advantages and features will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an elevational view of an electrochemical power generating system of the present invention with portions broken away to show many of the components of the system;

Fig. 2 is a section on line 2-2 of Fig. 1, showing an end view of the second portion with portions broken away to show the elements of one of the cells;

Fig. 3 is a section on line 3-3 of Fig. 2 showing one of the cells;

Fig. 4 is a rear elevational view of one of the cells of the power generating system of Fig. 1;

Fig. 5 is a view of one of the anodes of the power generating system of Fig. 1;

Fig. 6 is an elevational view of the row of cells of the power generating system of Fig. 1 with opposite ends of the row of cells being urged together;

Fig. 7 is an elevational view similar to Fig. 6 except the anodes have been consumed and the cells have been compressed;

Fig. 8 is a schematic diagram of an alternative embodiment of an electrochemical power generating system of the present invention;

Fig. 9 is a flow chart showing operation of the microprocessor of the power generating system of Fig. 8;

Fig. 10 is a battery power versus time chart of the metal-air cell battery of the power generating system of Fig. 8 as electrolyte is pulsed through the cells;

Fig. 11 is a cell temperature versus time chart of a metal-air cell of the power generating system of Fig. 8 as electrolyte is pulsed through the cell;

Fig. 12 is a schematic diagram of the power system in a deactivated position;

Fig. 13 is a schematic diagram of the power system during warm-up, immediately after being activated;

Fig. 14 is a schematic diagram of the power system during normal operation;

Fig. 15 is a schematic diagram of the power system during initial shut-down, immediately after being deactivated;

Fig. 16 is a cross-sectional view of an alternative embodiment of a metal-air cell similar to the cell of Fig. 3 except the cell of Fig. 16 has two cathodes;

Fig. 17 is a partial front elevational view of an alternative embodiment of a metal-air cell having an openable top;

Fig. 18 is a section view taken along line 18-18 of Fig. 17;

Fig. 19 is a top plan view of the metal-air cell of Fig. 17;

Fig. 20 is an exploded perspective view of a cathode and wall of the pouch of the metal-air cell of Fig. 17; and

Fig. 21 is a cross-sectional view similar to the view of Fig. 16 of an alternative embodiment of a metal-air cell.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figs. 1-3, an electrochemical power generating system of the present invention, generally indicated at 20, is shown to have a base unit, constituting a first portion, generally indicated at 22, and a replaceable fuel unit, constituting a second portion, generally indicated at 24. The base unit 22 includes a housing 26, an electrolyte pump 28 within the housing 26, and a controller 30, constituting means for controlling operation of the pump 28. The fuel unit 24 comprises a housing 32 and a row of metal-air cells 34 electrically interconnected within housing 32. Each cell 34 includes a flexible pouch 36, a metal anode 38 within pouch 36, an air cathode 40, and spacers 42 for preventing anode 38 from contacting cathode 40. Pouch 36 has an electrolyte inlet port 44 and an electrolyte discharge port 46 for passage of electrolyte through pouch 36 and between anode 38 and cathode 40. A supply manifold 48 is within housing 32 for delivering electrolyte to the cells 34. The manifold 48 has

an intake port 50 and a plurality of discharge ports 52. The discharge ports 52 are in fluid communication with the inlet ports 44 of the cells 34 via a plurality of flexible fluid lines 54 so that electrolyte flowing through manifold 48 is directed through the inlet ports 44 of the cells 34. Also within housing 32 is a discharge manifold 56 having a plurality of intake ports 58 and a discharge port 60. A plurality of flexible fluid lines 62 connect discharge ports 46 of cells 34 to intake ports 58 of discharge manifold 56. A conduit 64 connects discharge port 60 of discharge manifold 56 to an electrolyte reservoir 66 positioned below supply manifold 48. Electrolyte flows from cells 34, through discharge manifold 56, and then into reservoir 66.

As shown in Fig. 1, a conduit 68 connects reservoir 66 to a heat exchanger 70 (preferably a fin and tube type heat exchanger) within housing 26. Pump 28 is connected to heat exchanger 70 via a conduit 71 and to intake port 50 of supply manifold 48 via a conduit 72. Thus, reservoir 66 and intake port 50 of manifold 48 are operatively connectable with the electrolyte pump 28 for fluid communication therewith so that pump 28 is able to draw electrolyte from reservoir 66 and force it into manifold 48. The electrolyte flows through cells 34 and electrochemically couples anodes 38 and respective cathodes 40. The flowing electrolyte also flushes reaction products from cells 34. Hydrogen gas generated by the reaction in cells 34 is carried to discharge manifold 56 by the electrolyte flowing through cells 34. The hydrogen gas bubbles out of the electrolyte in discharge manifold 56 and is vented through a vent hole 67 in manifold 56. Preferably, reservoir 66 is releasably connected to conduit

68 and conduit 72 is releasably connected to intake port 50 with quick-release fluid line connectors 74 and 76, respectively. Connectors 74 and 76 releasably attach fuel unit 24 to base unit 22 so that fuel unit 24 can be quickly attached to and detached from base unit 22. When anodes 38 are consumed, fuel unit 24 can be detached quickly from base unit 22 and replaced with a new fuel unit. Thus, power generating system 20 can be rapidly refueled, thereby minimizing down time. The used fuel unit 24 can then be refueled or reclaimed.

As shown in Figs. 3 and 4, cathode 40 has a substrate 78 and a current collector 80 attached to substrate 78. Substrate 78 has an outer face 82 and an inner face 84. Substrate 78 is a sheet material (such as POREX® available from Porex Technology Corp. of Georgia) formed with or embedded with an activated carbonaceous material and is air-permeable and electrolyte-impermeable. Current collector 80 is a thin layer of electrically conductive material, such as nickel, silver, or stainless steel, formed on one of the faces of substrate 78. Preferably, current collector 80 comprises a printed circuit on one of the faces of substrate 78 in a pattern having a dendritic web extending from a common conductor 86. The printed circuit may be formed on substrate 78, for example, by chemical etching, photo screening, or hot-foil stamping.

Pouch 36 is flexible and compressible and has first and second opposed walls 88 and 90, preferably formed of a polymeric material, such as polyethylene. The first wall 88 has a window opening 92 with the margins of substrate 78 permanently sealed to first wall 88 all around window opening 92. It is to be understood that window 92

may be a specially treated portion of wall 88. In either case, only the window area is active and functions as a cathode. The exposed region of substrate 78, i.e., the portion of substrate 78 encompassed by window opening 92, is the portion of substrate 78 which performs the cathodic function. Preferably, the margins of substrate 78 are bonded to first wall 88 by an appropriate adhesive. Alternatively, substrate 78 could be secured to first wall 88 by heat sealing. Preferably, the carbonaceous material is deposited only in the interior region of substrate 78 with the margins of substrate 78 being relatively free of such material. Having no (or little) carbonaceous material at the margins of substrate 78 enhances securement of substrate 78 to first wall 88. Substrate 78 may also be formed of fibrillated polyolefin having a sufficient amount of carbonaceous material in the interior region to provide the desired electrolytic reactions and having a reduced amount of carbonaceous material (or none at all) at the margins to enhance securement to first wall 88. The ratio of carbonaceous material to fibrillated polyolefin may increase gradually from the edges of substrate 78 to the center or may increase in an abrupt step. Alternatively, or additionally, the margins of substrate 78 may be impregnated with a substance (such as polyethylene in solution) which promotes bonding to first wall 88.

Referring to Figs. 3 and 5, anode 38 is a generally flat plate of aluminum, aluminum alloy, or other suitable metal such as magnesium or zinc, having a first face, constituting a reaction face 94, and a second face 96. The reaction face 94 opposes the inner face 84 of the cathode 40. An electrically conductive raised dendritic

pattern 98 is on second face 96 and extends from a common conductor 100. The dendritic pattern 98 of anode 38 comprises a tapering main stem 98a that starts at the common terminal conductor 100 and extends substantially across the second face 96 and a plurality of tapering branches 98b extending from main stem 98a. During operation of power generating system 20, anode 38 is consumed from its reaction face 94 toward its second face 96. If the anode is not consumed uniformly along the reaction face or if the thickness of the anode is not uniform (i.e., if there are thin spots), breaks or openings can form in the anode before it is substantially consumed. These breaks can isolate portions of the anode from the conductor, resulting in a partial or total reduction of energy output from the cell. To prevent isolation of these portions from the conductor, the dendritic pattern 98 protrudes from second face 96. Even if breaks or openings form in anode 38, dendritic pattern 98 keeps all portions of anode 38 in electrical contact with conductor 100. Thus, pattern 98 provides structural integrity and electrical communication across anode 38 to conductor 100 as the metal in anode 38 is consumed. Preferably, anode 38, including dendritic pattern 98, is formed from a single homogeneous piece of metal.

Spacers 42 are positioned between cathode 40 and the reaction face 94 of anode 38 to physically isolate anode 38 from cathode 40 by a predetermined spacing, typically on the order of about 3mm (120 mils). Spacers 42 may be nubs or bosses integral with substrate 78 and projecting from the inner face 84 of substrate 78. Alternatively, anode-cathode spacing may be maintained by a non-conducting lattice of

criss-crossing members as described below with reference to Fig. 20.

Referring to Figs. 6 and 7, the entire row of cells 34 is preferably surrounded by a resilient harness having banding straps 102 and tension springs 104 (only one of which is shown). The straps 102 extend around opposite ends of the row of cells 34 and are connected together by springs 104. Although not shown, it is to be understood that the harness is electrically insulated from terminal connectors 100 and 86. Springs 104 are tensioned to urge opposite ends of the row of cells 34 toward each other. Since pouch 36 of each cell 34 is flexible, the harness urges the anode 38 and cathode 40 of each cell 34 toward each other with spacers 42 (see Fig. 3) of each cell being squeezed by the reaction face 94 of anode 38 and the inner face 84 of cathode 40. Fig. 6 shows the row of cells 34 before anodes 38 have begun to be consumed and, therefore, cells 34 and their respective anodes are relatively thick. Fig. 7 shows the row of cells 34 with most of each anode being consumed and, therefore, cells 34 and their respective anodes are relatively thin and the row of cells 34 is compressed. Preferably, fluid lines 54 and 62 are flexible to accommodate contraction or compression of the row of cells 34. Alternatively, the intake and discharge manifolds could each have a bellows-type configuration which contracts as the row of cells 34 contracts. Since anode 38 and cathode 40 are being squeezed against spacer 42, the distance between the inner face 84 of cathode 40 and the reaction face 94 of anode 38 remains substantially constant (i.e., the same as the thickness of spacers 42) during consumption of anode 38. Since the distance between cathode

40 and reaction face 94 remains substantially constant, consumption of anode 40 does not result in a decrease in voltage and power output of the cell. Also, this distance remains substantially constant during consumption of anode 38 regardless of the initial thickness of anode 38. With thicker anodes, the metal-air cell battery is operable for longer periods between refueling and without an appreciable reduction in power output.

Although harness 103 constitutes the preferred means for urging the anode and cathode of each cell toward each other, it is to be understood that other means may be employed without departing from the scope of this invention. Examples of other ways of urging opposite ends of the row of cells 34 together include: tensioned elastomeric bands placed around the row of cells; interacting wedges at ends of the row of cells which produce a compressive force against the ends; two rigid end plates engaging opposite ends of the row of cells with the end plates being urged toward each other by tensioned springs; compression springs at one end of the row of cells which urge the one end toward the other end; an inflatable bag at one end of the row of cells which, upon inflation, urges the one end toward the other end; or a hydraulic cylinder at one end of the row of cells which, upon being pressurized, urges the one end toward the other end.

Referring again to Fig. 1, the base unit 22 further includes an air pump 108, constituting a depolarization air system, for forcing slightly compressed air across the cathodes. A plurality of inter-cell spacers or separators 106 (also shown in Figs. 2, 3 and 6), preferably formed of a synthetic resin, are interposed

between adjacent cells 34 to provide air spaces adjacent the cathodes so that the depolarizing air can circulate around the cells and to the cathodes. The circulation of air around cells 34 also helps to cool the cells. The thickness of the spacers 106 between cells 34 may vary so that the sizes of the spaces between adjacent cells varies to achieve variable cooling of the cells. For example the inter-cell spacing can decrease from one end of the row of cells to the other, or the inter-cell spacing can decrease from the center of the row of cells toward the ends of the row. The thickness of spacers 106 is selected generally to achieve equalization of the temperatures of the cells 34 in the row of cells.

A cooling fan 110 is within housing 26 for forcing cooling air across the fins of heat exchanger 70 to cool electrolyte within heat exchanger 70. A lead-acid battery 112, or other suitable secondary battery, operates pump 28, controller 30, and pump 108 and fan 110 during start-up of the metal-air cell battery.

Referring to Figs. 1, 4 and 6, the conductors 86 of cathodes 40 are directly connected to the conductors 100 of anodes 38 of adjacent cells thereby connecting cells 34 in series to each other. Battery stack end cathode conductor 86 is connected to negative contact pad 115a via an electric cable (not shown). Battery stack end anode conductor 100 is connected to positive contact pad 115b via electric cable 113b. Positive and negative electrical contact pads 115a and 115b (see Fig. 2) extend through a side wall 114 of housing 32. The contact pads 115a and 115b are interengageable with two like polarity contact pads (not shown) extending through a side wall 116 of housing 26 for

electrically connecting the metal-air cell battery to an external load and to lead-acid battery 112. Base unit 22 further includes positive and negative load engageable terminals (not shown) through a second side wall 118 of housing 26 and suitable conductors (not shown) for providing electrical energy to the terminals.

Another embodiment of an electrochemical power generating system of the present invention, generally indicated at 220, is shown schematically in Fig. 8. Power generating system 220 comprises a fluid system, a gas system, and an electrical system. The fluid system includes a sump 224, an electrolyte filter 226, a heat exchanger 228, and a reversible-flow pump 230 for moving electrolyte through a plurality of metal-air cells, generally indicated at 222. Electrolyte flows from cells 222 through a conduit 232 and to sump 224 which includes a plurality of baffles 224a for collection of reaction products discharged from the cells. Electrolyte from sump 224 flows through a conduit 234 to filter 226, which filters reactants, generated in cells 222, from the electrolyte. Electrolyte moves from filter 226 to heat exchanger 228 via a conduit 236. Heat exchanger 228 is preferably a fin and tube type heat exchanger and includes a cooling fan 229 for moving air across the fins for cooling the electrolyte when the electrolyte exceeds a predetermined temperature. Heat exchanger 228 is in fluid communication with pump 230 via a conduit 238. An electrolyte reservoir 240 is in fluid communication with conduit 238 via a conduit 242. Electrolyte from reservoir 240 is introduced into the circulatory system only if and when the electrolyte in sump 224 falls below a minimum acceptable level. The reservoir

240 maintains proper electrolyte level in cells 222. Electrolyte from pump 230 flows through a conduit 244 to cells 222 via a concentration sensor 250. The electrolyte may be an aqueous solution of potassium hydroxide (KOH), sodium hydroxide (NaOH), sodium chloride (NaCl), or any other suitable electrolyte. The electrolyte in sump 224 maybe seeded with micro-crystals of the anticipated reaction products, such as $Al(OH)_3$ in aluminum air cells where the electrolyte is KOH, to cause the reaction products to precipitate out of the electrolyte solution and facilitate the trapping of these products in sump 224.

Power generating system 220 also includes an electrolyte concentrate reservoir 246, a solenoid-actuated metering valve 248, and an electrolyte concentration sensor 250. Concentrate reservoir 246 is in communication with conduit 244 via two conduits 252 and 254 and valve 248. Sensor 250 senses concentration of electrolyte and may be, for example, a conductivity sensor which measures the conductivity of the electrolyte solution to gauge the electrolyte concentration. Alternatively, sensor 250 may be a pH sensor which measures the pH of the electrolyte solution to gauge the electrolyte concentration. When the con-centration of the electrolyte falls below a predetermined value, valve 248 meters concentrated electrolyte from reservoir 246 to conduit 244. The concentrated electrolyte increases the concentration of electrolyte transported to cells 222. Thus, weak electrolyte is automatically replenished.

An air pump 256 forces depolarizing air to cells 222. The circulating air is passed through a filter 257 to remove contaminants, particularly carbon particles, that

might contaminate the system. The electrochemical reaction in the cells produces hydrogen gas which is vented from the cells by a conduit 258. Conduit 258 communicates with a catalytic bed 260. Air and byproduct gasses, such as hydrogen, from cells 222 are forced to pass through catalytic bed 260 where the hydrogen is recombined with atmospheric oxygen to form water. The water drains from catalytic bed 260 to sump 224 through a conduit 262, where it replenishes moisture lost from the electrolyte during operation of cells 222. Alternatively, or in addition, a vent can be provided to allow H_2 gas to escape, with or without the assistance of air pump 256 or fan 229.

Power generating system 220 has a controller 264, preferably in the form of a microprocessor, for controlling pump 230, cooling fan 229, metering valve 248, and air pump 256. A lead-acid battery 266 or any suitable supplemental battery operates controller 264 and pump 230 during start-up of power generating system 220. During operation of power generating system 220, i.e., when power is being supplied to a load, battery 266 serves as an accumulator for accommodating power surges demanded by the load above the normal output limits of cells 222. Battery 266 is normally connected in parallel with the row of cells 222 via controller-controlled switches 267 described in more detail below. Lead-acid battery 266 provides power to activate generating system 220, and to complete shut-down operations after a master switch 269 is opened. A voltmeter 261 and ammeter 263 are provided to give the operator an indication of the system voltage and the amount of current being drawn as power generating system 220 is loaded. Power generating system 220 could also be provided with other indicators,

such as temperature indicators, electrolyte fluid level indicators, and a fuel indicator indicating the thickness of the anodes or the operating time remaining.

Referring to Fig. 8 and the flow chart of Fig. 9, the operation of pump 230 and fan 229 by controller 264 will be described. Controller 264 enables cells 222 to rapidly reach full power even when the electrolyte is initially cold. A first temperature sensor 268 senses electrolyte temperature in the circulatory system. A second temperature sensor 270 is in at least one of the cells for measuring the temperature of electrolyte in the cells. Initially, no electrolyte is in the cells of battery 222. When the power generating system 220 is turned on, controller 264, at step 272, compares the system temperature, as measured by first sensor 268, with a predetermined temperature T_S. If the system temperature does not exceed temperature T_S, controller 264 activates pump 230 for a brief predetermined duration D_1 at step 274. This brief activation causes a charge (volume) of electrolyte to be pumped into the cells. The electrolyte charge is held statically (or near statically) within the cells so that it quickly absorbs heat from the electrochemical reaction taking place between the cathodes and anodes. In step 276, after the charge is pumped into the cells, controller 264 compares the electrolyte temperature in the cells, as measured by second sensor 270, with a predetermined temperature T_1. If the cell temperature does not exceed temperature T_1, controller 264 reexecutes step 274, and repeatedly does so until the cell temperature exceeds temperature T_1. When temperature T_1 is exceeded, controller 264 returns to start at step 278. If the system temperature does not exceed temperature T_S, controller 264

will repeat steps 272-278. As steps 272-278 are repeated, a fresh charge of electrolyte is pumped into the cells and the old charge (i.e., the one heated during the previous cycle) is forced into sump 224. Controller 264 will repeat steps 272-278, incrementally elevating the temperature in the fluid system (including reservoir 240), until the system temperature exceeds temperature T_S. By pulsing charges of electrolyte into the cells and allowing them to remain static until they reach an optimal temperature, cells 222 can operate at near full power without waiting for all the electrolyte in the system to heat up. Also, since cells 222 quickly operate at near full power, the system electrolyte is heated at a much faster rate than could be accomplished with a continuous flow system. Graphs representing battery power vs. time and cell temperature vs. time during electrolyte pulsing are shown in Figs. 10 and 11.

When controller 264 determines that the system temperature exceeds temperature T_S, pump 230 is operated for continuous flow in step 280. In step 282, controller 264 compares the electrolyte temperature in the cells, as measured by second sensor 270, with a predetermined temperature T_3. If the cell temperature exceeds temperature T_3, controller 264, in step 284, energizes cooling fan 229 to cool electrolyte passing through heat exchanger 228. If in step 282, the cell temperature does not exceed temperature T_3, controller 264 compares the cell temperature with a predetermined temperature T_2 (which is less than temperature T_3) in step 286. If the cell temperature is lower than temperature T_2, controller 264 signals a relay for deactivating cooling fan 229 in step 288. Controller 264 then returns to start in step 290. Temperatures T_2 and T_3

are selected to maintain a stable temperature for the electrolyte solution within the optimum operating range of the system. Thus, controller 264 selectively energizes fan 229 for controlling cooling of the electrolyte.

Controller 264 controls metering valve 248 in response to electrolyte concentration sensor 250, opening valve 248 to release concentrated electrolyte into conduit 244 to boost the concentration of electrolyte when sensor 250 detects that the concentration has fallen below a predetermined level. Controller 264 may further control pump 230 by varying the pulse duration D_1 as a function of electrolyte temperature. For example, controller 264 could cause duration D_1 to increase as the system temperature increases. Also, controller 264 could control pump 230 as a function of some operating condition of cells 222 other than electrolyte temperature. For example, pump 230 may be operated as a function of a voltage generated by cells 222.

As noted above, controller 264 also controls operation of power generating system 220 during shut-down. When a master switch 269 is manually set so that system 220 is deactivated, controller 264 initially connects lead-acid battery 266 across the row of cells 222, applying reverse polarity voltage to inhibit electron flow and thus help protect the anodes in cells 222 from further electrochemical depletion. However, if system 220 is not turned on again within a predetermined duration D_2 (e.g., one hour), then a timing switch within controller 264 disconnects the lead-acid battery 266 from cells 222 and sends a signal to cause pump 230 to operate in reverse pump mode to draw electrolyte from the cells and force it back through heat exchanger 228

and into sump 224. After a predetermined duration, or when cells 222 are substantially empty, controller 264 deactivates pump 230.

The start up and shut down operations of system 220 are illustrated in Figs. 12-15. In Fig. 12, system 220 is shown in a deactivated state, with no power being supplied to the load. In Fig. 13 the system is shown immediately after switch 269 has been moved to the position shown thereby causing current from lead-acid battery 266 to be provided to controller 264, and causing a solenoid actuated master contactor 271 to connect battery 266 to the load, switch 273, ganged to switch thereby connects a first plurality 275 of cells 222 (constituting a first part of the row of cells 222) to a second plurality 277 of cells 222 (constituting a second part of the row of cells 222) in series. In the position shown, switch 269 also energizes a solenoid 279 thereby to reposition two switches 281 and 283. The repositioning of switch 281 causes battery 266 to be connected to the row of cells 222 in series, and the repositioning of switch 283 causes battery 266 and the row of cells 222 to be connected through a current-limiting resistor 285 to ground. Thus, battery 266 provides a current, limited by resistor 285, to heat cells 222 and to depassivate the anodes, breaking up films (such as an oxidation layer) that may form on the anodes. When cells 222 have been warmed, a normally closed thermal switch 287 opens, de-energizing solenoid 279 and repositioning switches 281 and 283. As shown in Fig. 14, when switch 281 is repositioned, it connects the negative terminal of the row of cells 222 to ground and switch 283 connects the positive terminal of the row of cells to the load, in parallel with

battery 266. Battery 266 and the row of cells can thus provide current to the load in parallel. However, the higher voltage output of the row of cells at maximum rated current levels exceeds the voltage of battery 266, and thus the row of cells usually provides all of the power output and also keeps battery 266 charged.

When the system 220 is shut down by moving switch 269 to the position shown in Fig. 15, master contactor 271 is de-energized, disconnecting the output from the load. Switch 269 also initiates operation of a corrosion inhibit timer 289 which temporarily closes two normally open switches 291 and 293, and repositions switch 273 separating first plurality 275 of cells and second plurality 277. Closing switch 291 connects battery 266 through a current-limiting resistor 295 to the positive terminal of the first plurality 275 of cells, the negative terminal of which is connected to ground. Closing switch 293 connects the negative terminal of the second plurality 277 of cells through a current-limiting resistor 297 to ground, the positive terminal of which is already connected to battery 266. With switches 291 and 293 closed, battery 266 provides positive bias voltage to protect the anodes in cells 222 from consumption. After a predetermined period, corrosion inhibit timer 289 sends a signal to controller 264 to open switches 291 and 293. Controller 264 then activates pump 230 in reverse mode to drain the electrolyte into sump 224, to prevent further consumption of the anodes.

Another embodiment of a metal-air cell, generally indicated at 334, is shown in Fig. 16. Cell 334 includes a flexible pouch 336, a metal anode 338 within pouch 336, two air cathodes 340, and two spacers 342 for preventing

cathodes 340 from contacting anode 338. The primary difference between cell 334 and cell 34 is that cell 334 has two cathodes. Each cathode 340 has a substrate 378 and a current collector 380. Each substrate 378 is air-permeable and electrolyte-impermeable. Anode 336 has a first reaction face 394a opposing the inner face of one cathode and a second reaction face 394b opposing the inner face of the other cathode. Preferably, reaction faces 394a and 394b are both generally planar to provide flat reaction surfaces. Pouch 336 has first and second opposed walls 388 and 390, having first and second windows 392a and 392b, respectively. Spacers 342 are electrolyte-resistant non-conductive fibrous sheets formed of randomly oriented fibers and preferably have a thickness of approximately 3mm. Alternatively, spacers 342 may be knitted, woven, felted, etc., and may be formed of nylon, polyamide fusing web, polyester, etc. Having cathodes opposing both faces of anode 338 doubles the reaction surface area and effectively doubles the power output of cell 334.

Another embodiment of a metal-air cell, generally indicated at 400, is shown in Figs. 17-20. Cell 400 comprises a flexible pouch 402 having first and second walls (or panels) 404 and 406, the perimeters of which are sealed together to form a pouch having an open top. First and second panels 404 and 406 are air-permeable and electrolyte-impermeable. First and second films 408 and 409 of cathodic material, such as an activated carbonaceous material, are deposited on or embedded in the inner surfaces of first and second panels 404 and 406, respectively, and first and second current collectors 410 and 411 are secured to the inner surfaces in contact with films 408 and 409. Panels

404 and 406 constitute substrates for films 408 and 409 and support current collectors 410 and 411. Panel 404, film 408, and current collector 410 constitute a first air cathode 412 having an inner face 414; panel 406, film 409, and current collector 411 constitute a second air cathode 413 having an inner face 415. Within pouch 402 is a metal anode 416, having first and second reaction faces 418 and 420, and spacers 422 and 423. The first face 418 of anode 416 opposes inner face 414 of cathode 412 and the second face 420 opposes inner face 415 of cathode 413. Spacer 422 is between inner face 414 and first face 418 and spacer 423 is between inner face 415 and second face 420 for preventing anode 416 from contacting cathodes 412 and 413. Each spacer 422, 423 comprises a non-conducting lattice of criss-crossing members with spacer elements preferably in the form of cones 422a, 423a spaced on the lattice and positioned with respect to each other. Cones 422a, 423a have tapering cross sections to minimize their "foot print" on the active surfaces of the anode, i.e., to minimize loss of active surface of the anode, while assuring uniform separation between the anode and cathodes. It is to be understood that the spacer elements could alternatively have a pyramidal form or other suitable form. Each current collector has a conductive rectangular frame 424 surrounding one of the films 408 or 409, an electrical terminal connector 426 adjacent a corner of frame 424, and a plurality of conductive filaments 428 each extending from electrical connector 426 to frame 424. As an alternative to the filaments, each current collector may have a grid pattern or any other suitable pattern. Connector 426 extends through pouch 402 at the sealed perimeter.

Pouch 402 includes an inlet 430 and an outlet 432 to allow electrolyte solution to be circulated through cell 400. Inlet 430 is preferably located generally adjacent the bottom of pouch 402 at the sealed perimeter, and outlet 432 is preferably located generally adjacent the top of pouch 402 at the sealed perimeter to cause thorough circulation of the electrolyte solution from inlet 430, up and across cell 400, to outlet 432. Elongate, resilient sealing beads 438 and 440 are fixedly secured to panels 404 and 406, respectively. The beads 438 and 440 are adjacent to and extend along the opening at the top of pouch 402 and are engageable with each other to seal the top of the pouch. An elongate clamp 442 fits over beads 438 and 440 to releasably compress the beads together to close and seal pouch 402. An electrical terminal connector 444 extends upwardly from anode 416 and between sealing beads 438 and 440 and through a slot 446 at one end of clamp 442. Sealing beads 438 and 440 are sufficiently yieldable to accommodate connector 444. Preferably, an end cap 447 is placed over the slotted end of clamp 442 to secure the clamp on the pouch. Clamp 442 is easily removed from pouch 402 to allow opening of the pouch to remove the remainder of the spent anode, and install a replacement anode. Clamp 442 and sealing beads 438 and 440 constitute means for releasably closing the top of the pouch to seal against leakage of electrolyte therethrough.

Although cell 400 has been described as having two cathodes, it is to be understood that activated carbonaceous material may coat or be embedded in the entire inner surface of the pouch and a current collector may blanket the entire inner surface of the pouch so that the pouch, carbonaceous

material and current collector form an active cathode which envelops the anode.

Another embodiment of a metal-air cell, generally indicated at 534, is shown in Fig. 21. Cell 534 includes a flexible pouch, generally indicated at 536, a metal anode 538 within pouch 536, two air cathodes, generally indicated at 540, and two spacers 542 for preventing cathodes 540 from contacting anode 538. Cell 534 is similar to cell 334 shown in Fig. 16 in that both have two cathodes. Pouch 536 comprises two panels 588 and 590, the perimeters of which are joined together to form a pouch having an open top, similar to pouch 402 shown in Figs. 17-20. Panels 588 and 590 are air-permeable and electrolyte-impermeable and may be of a microporous metal foil, such as stainless steel, having pores sufficiently large to permit air to pass therethrough and sufficiently small to prevent electrolyte from passing therethrough. A suitable material is microporous stainless steel available from Hruden Laboratories of Woodinville, Washington. Films 578 of cathodic material, such as an activated carbonaceous material, are deposited on the inner surfaces of panels 588 and 590. Panels 588 and 590 constitute substrates for films 578. Preferably, current collectors 580 are in contact with the inner surface of each film 578 and are electrically isolated from the foil panels 580 and 590. Alternatively, the foil panels themselves may constitute current collectors. Panels 588 and 590, films 578, and current collectors 580 constitute air cathodes 540. Anode 536 has first and second reaction faces 594a, 594b opposing the inner faces of cathodes 540. Spacers 542 are preferably the same as spacers 422, 423 as discussed above with reference to Figs. 17-20. Alternatively, the spacers

may be formed of randomly oriented fibers, or be knitted, woven, felted, etc., and may be formed of nylon, polyamide fusing web, polyester, etc.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

CLAIMS

What is claimed is:

1. A power generating system comprising a metal-air cell, the metal-air cell including:

a flexible, collapsible pouch having first and second opposed walls, at least one of which includes an air-permeable and electrolyte-impermeable air cathode;

a metal anode within the pouch and surrounded thereby and having a first reaction face opposing the cathode; and

a spacer between the cathode and the reaction face of the anode for preventing the anode from contacting the cathode, the spacer separating the anode and the cathode by a predetermined spacing.

2. The power generating system according to claim 1, wherein the pouch has an opening with opposed elongate sealing beads adjacent the opening, and a clamp for compressing the sealing beads together to close the opening in the pouch.

3. The power generating system according to claim 2 further comprising an anode terminal projecting from the anode, and wherein the sealing beads are of sufficient size and resiliency to allow the anode terminal to extend between them to the exterior of the pouch, and wherein the

clamp has an opening to accommodate the projecting anode terminal.

4. The power generating system according to claim 1 wherein the pouch comprises two panels of a gas-permeable, electrolyte-impermeable, material joined together along their edges to form a pouch with an opening therein.

5. The power generating system according to claim 4, further comprising an elongate, resilient sealing bead on each panel adjacent the opening of the pouch, and a clamp for compressing the sealing beads together to close the pouch.

6. A power generating system comprising a stack of metal-air cells according to claim 1, a harness surrounding the stack of cells, and a spring for tensioning the harness to compress the stack of cells, to maintain the predetermined anode-cathode spacing determined by the spacers in the cell, as the anode in each cell is consumed.

7. A power generating system comprising a stack of metal-air cells according to claim 1, and a plurality of air gap spacers between the cells in the stack for separating the cells with an air gap, the air gap spacers being sized so that the size of the air gap between the cells varies.

8. A power generating system comprising a stack of metal-air cells according to claim 1, and a plurality of

air gap spacers between the cells in the stack for separating the cells with an air gap, the air gap spacers being sized so that the size of the air gap between the cells decreases from one end of the stack toward the other.

9. A power generating system according to claim 1 further comprising a highly conductive terminal extending from the anode, the anode comprising a generally flat metal plate having a first face, a second face, and a raised dendritic pattern protruding from the second face, the dendritic pattern comprising a main stem extending from the conductive terminal substantially across the plate, and a plurality of branches extending from the main stem, the pattern providing structural integrity and electrical communication across the anode plate to the terminal as the metal in the plate is consumed.

10. A power generating system according to claim 1 wherein the first wall has a window opening therein and wherein the air cathode is permanently sealed to the first wall all around the window opening.

11. A power generating system according to claim 10 wherein the current collector comprises a thin web of electrically conductive material formed on one of the faces of the substrate.

12. A power generating system according to claim 10 wherein the current collector comprises an electrically conductive dendritic web extending from a common conductor.

13. A power generating system according to claim 12 wherein the current collector comprises a printed circuit on one of the faces of the substrate.

14. A power generating system according to claim 10 further comprising:

a second window opening in the second wall;

a second air cathode permanently sealed to the second wall all around the second window opening; and

a spacer between the second cathode and the anode for preventing the anode from contacting the cathode.

15. A power generating system according to claim 1 wherein said spacer comprises an electrolyte-resistant non-conductive fibrous sheet formed of randomly oriented fibers.

16. A power generating system according to 1 wherein the cathode includes a carbonaceous material.

17. The power generating system according to claim 1, further comprising an inlet and an outlet in the pouch to allow an electrolyte solution to be circulated through the cell, between the anode and the cathode.

18. The power generating system according to claim 17 further comprising a circulatory system for delivering electrolyte solution to the inlet of the cell and removing electrolyte solution from the outlet of the cell, the circulatory system including a pump.

19. The power generating system according to claim 18 wherein the circulatory system includes a heat exchanger through which the electrolyte solution circulates, and further comprising a cooling fan for forcing cooling air over the heat exchanger, a sensor for monitoring the temperature of the electrolyte solution circulating in the circulatory system, and a controller for turning on the fan when the temperature of the electrolyte solution exceeds a predetermined temperature T_3, and for turning off the cooling fan when the temperature of the electrolyte solution is less than a predetermined temperature T_2.

20. The power generating system according to claim 18 further comprising a supplemental battery adapted for connection in parallel with the cell, and sized to provide operating power for the system and supplementary power to the system during periods of peak current demand by an external load.

21. The power generating system according to claim 20 comprising a controller for temporarily connecting the supplemental battery in series with the cell when the power generating system is turned on to facilitate start up of the power generating system.

22. The power generating system according to claim 18 further comprising a sump in the circulatory system with baffles for trapping solid particles that form in the electrolyte solution.

23. The power generating system according to claim 18 further comprising an electrolyte filter for removing particles from the circulating electrolyte solution.

24. The power generating system according to claim 18 further comprising a depolarizing air pump for circulating air to the cathode of the cell.

25. The power generating system according to claim 18 further comprising a temperature sensor for sensing the temperature of the electrolyte solution, and means for selectively energizing the circulatory system as a function of the sensed temperature.

26. A power generating system comprising a stack of metal-air cells according to claim 17, and a circulatory system for delivering electrolyte solution to the inlets of the cells, said stack being provided as a separable, replaceable component of the system, and wherein the stack is connected to the circulatory system with quick-connect connectors.

27. The power generating system according to claim 26 wherein the stack comprises an inlet manifold connected to the inlets of each cell, and an outlet manifold connected to the outlets of each cell, and wherein the connection between the stack and the circulatory system is a connection between the inlet manifold and the circulatory system, and a connection between the outlet manifold and the circulatory system.

28. A power generating system comprising a first unit including a stack of metal-air cells according to claim 17, and a second unit, releasably connectable to the first unit, the second unit comprising a circulatory system for delivering electrolyte to the inlets of the cells and removing electrolyte from the outlets of the cells, the circulatory system including a pump, and a controller for controlling the circulatory system.

29. The power generating system according to claim 28 wherein when the power generating system is turned off, the controller causes the circulatory system to remove the electrolyte from the cells to conserve the anodes.

30. The power generating system according to claim 28 wherein the first unit comprises an electrolyte reservoir, and wherein when the first and second units are connected, the circulatory system draws electrolyte from the reservoir in the first unit, and delivers it to the inlets of the cells in the first unit.

31. The power generating system according to claim 28 wherein when the power generating system is turned off, the controller causes the circulatory system to draw the electrolyte from the outlets of the cells into the reservoir.

32. The power generating system according to claim 28 wherein the power generating system includes a supplemental battery, and wherein the controller is adapted for connecting the supplemental battery across the stack

with reverse polarity for a predetermined time when the power generating system is turned off to inhibit electron flow and so preserve the anodes in the cells.

33. The power generating system according to claim 32 wherein the controller is adapted to cause the circulatory system to draw the electrolyte from the cells to preserve the anodes if the power generating system is not turned on again within the predetermined time.

34. The power generating system according to claim 28 wherein the second unit further comprises a depolarizing air pump for pumping air between the cells in the first unit.

35. The power generating system according to claim 28 wherein the second unit comprises a secondary battery for powering the second unit, the secondary battery being recharged by the stack.

36. A power generating system comprising a stack of metal-air cells according to claim 17, and a sealed electrolyte reservoir under compression so that when the seal is broken, the electrolyte is charged into the cells in the stack.

37. The power generating system according to claim 1 wherein said pouch has an openable top.

38. The power generating system according to claim 37 further comprising means for releasably closing

said top to seal against leakage of electrolyte therethrough.

39. The power generating system according to claim 38 wherein said closing means comprises a first sealing bead along a top edge of the first wall, a second sealing bead along a top edge of the second wall, said first bead being engageable with the second bead to seal the top of the pouch.

40. The power generating system according to claim 39 wherein said closing means further comprises means for urging the first and second beads against each other.

41. The power generating system according to claim 40 wherein said urging means comprises a clamp for compressing the sealing beads together.

42. The power generating system according to claim 1 wherein the anode comprises a generally flat plate having a first face, a second face and a raised dendritic pattern protruding from the second face for providing structural integrity and electrical communication across the plate, said first face comprising the first reaction face.

43. The power generating system according to claim 1 wherein the pouch is air-permeable and electrolyte-impermeable and the air cathode comprises at least a portion of one of the walls.

44. The power generating system according to claim 43 wherein the cathode further comprises a current collector and wherein the first wall comprises a substrate carrying the current collector.

45. The power generating system according to claim 44 further comprising a second air cathode, said second air cathode comprising at least a portion of said second wall and a second current collector, said second wall comprising a second substrate carrying said second current collector.

46. A metal-air cell battery having a row of collapsible metal-air cells arranged in face-to-face relationship and electrically interconnected, each cell including a flexible, collapsible pouch, a metal anode within the pouch and having a reaction face, an air cathode having an outer face and an inner face with the inner face opposing the reaction face, a spacer between the inner face of the cathode and the reaction face of the anode for preventing the anode from contacting the inner face of the cathode, an electrolyte intake port and an electrolyte discharge port for the pouch for passage of electrolyte through the pouch and between the anode and cathode, said battery further comprising means for urging opposite ends of the row of collapsible cells toward each other thereby to urge the anode and cathode of each cell toward each other so that the distance between the inner face of the cathode and the reaction face of the anode of each cell remains generally constant during consumption of the anode.

47. The metal-air cell battery according to claim 46 wherein the means for urging opposite ends of the row of cells toward each other comprises a resilient harness extending around the row of cells.

48. The metal-air cell battery according to claim 46 further comprising a plurality of inter-cell spacers between adjacent cells in the row of cells for providing air gaps between the adjacent cells.

49. A power generating system having a first portion including an electrolyte pump and electronic control means for controlling operation of the pump and a separable second portion, said second portion comprising:

a row of metal-air cells electrically interconnected together, each cell including a casing, a metal anode within the casing and having a reaction face, an air cathode having an outer face and an inner face with the inner face opposing the reaction face, a spacer between the inner face of the cathode and the reaction face of the anode for preventing the anode from contacting the cathode, an electrolyte intake port and an electrolyte discharge port in the casing for passage of electrolyte through the casing and between the anode and cathode;

a manifold having an intake port and a plurality of discharge ports in fluid communication with the electrolyte intake ports of the cells so that electrolyte flowing through the manifold is directed through the intake ports of the cells;

an electrolyte reservoir, said electrolyte reservoir and intake port of the manifold being operatively

connectable with the electrolyte pump for fluid communication therewith so that the pump is able to draw electrolyte from the reservoir and force it into the manifold;

means for operatively connecting the discharge ports of the cells with the reservoir so that electrolyte discharged from the cells flows to the reservoir; and

said second portion being releasably attachable to the first portion so that the second portion can be quickly attached to and detached from the first portion.

50. The power generating system according to claim 49 wherein the casing of each cell comprises a flexible, collapsible pouch and wherein the cells are arranged in face-to-face relationship, said power generating system further comprising means for urging opposite ends of the row of cells toward each other so that the distance between the inner face of the cathode and the reaction face of the anode of each cell remains generally constant during consumption of the anode.

51. The power generating system according to claim 50 wherein the means for urging opposite ends of the row of cells toward each other comprises a resilient harness extending around the row of cells.

52. The power generating system according to claim 51 further comprising a plurality of flexible conduits for directing electrolyte flowing through the manifold to the intake ports of the cells, each conduit having a first end connected to one of the discharge ports of the manifold

and a second end connected to one of the intake ports of the cells.

53. The power generating system according to claim 49 wherein the anode of each cell comprises a generally flat plate having a first face, a second face, and a raised dendritic pattern protruding from the second face for providing structural integrity and electrical conduction across the plate, the first face of each anode comprising the first reaction face of such anode.

54. The power generating system according to claim 49 further comprising a depolarization air system for feeding air to the cathode of each cell.

55. A power generating system comprising:

at least one metal-air cell;

an electrolyte reservoir;

electrolyte transport means for drawing electrolyte from the reservoir and moving it through the cell;

a first sensor for sensing an operating condition of the generating system; and

means for selectively energizing the electrolyte transport means as a function of the sensed operating condition whereby energizing the electrolyte transport means causes electrolyte to be drawn from the reservoir and transported to the cell.

56. The power generating system according to claim 55 wherein the first sensor is a temperature sensor for sensing the temperature of the electrolyte.

57. The power generating system according to claim 56 wherein the energizing means energizes the electrolyte transport means when sensed electrolyte temperature exceeds a predetermined temperature T_1.

58. The power generating system according to claim 55 further comprising means for cooling electrolyte and means for selectively energizing the electrolyte cooling means as a function of the sensed operating condition whereby energizing the electrolyte cooling means cools the electrolyte.

59. The power generating system according to claim 55 further comprising a catalytic converter for catalyzing the conversion to water of hydrogen produced by the cell.

60. The power generating system according to claim 55 wherein the means for selectively energizing the electrolyte transport means energizes the transport means for a predetermined duration D_1.

61. The power generating system according to claim 60 wherein the duration D_1 is a function of the sensed operating condition.

62. The power generating system according to claim 55 wherein the electrolyte transport means comprises a reversible pump.

63. The power generating system according to claim 55 wherein the electrolyte transport means comprises a pump and at least one conduit for conveying electrolyte from the pump to the cell.

64. A power generating system comprising:

a battery having at least one metal-air cell including a casing, a metal anode within the casing and having a reaction face, and an air cathode having an outer face and an inner face with the inner face opposing the reaction face; and

means for applying a bias voltage to the battery during periods when the battery is not supplying current to a load thereby to inhibit anode depletion, said voltage being of like polarity and of a potential at least equal to that of the battery.

65. The power generating system according to claim 64 wherein the source of the bias voltage is a secondary battery.

66. A power generating system for supplying power to an electrical load comprising:

a primary battery having at least one metal-air cell including a casing, an anode within the casing and having a reaction face, an air cathode having an outer face and an inner face with the inner face opposing the reaction

face, an electrolyte intake port in the casing for passage of electrolyte through the casing and between the anode and cathode, and an electrolyte discharge port in the casing; and

means for heating electrolyte within the battery when the temperature of the electrolyte is below a predetermined temperature.

67. The power generating system according to claim 66 wherein said heating means comprises a supplemental power source connected in series with the primary battery for selectively carrying the load whereby current from the supplemental power source passes through the primary battery o heat the electrolyte.

68. The power generating system according to claim 67 further comprising a controller for operatively connecting the primary battery and supplemental power source in series when the temperature of the electrolyte is below the predetermined temperature and for operatively connecting the battery and supplemental power source in parallel when the temperature is above the predetermined temperature.

69. The power generating system according to claim 68 further comprising a sensor for sensing electrolyte temperature within the primary battery, said controller being responsive to the sensor.

70. The power generating system according to claim 69 wherein the supplemental power source comprises a secondary battery.

71. A method of controlling a power generating system comprising a plurality of metal-air cells and a circulatory system for circulating an electrolyte solution through the cells, the method comprising:

sensing an operating condition of the generating system; and

selectively energizing the circulatory system as a function of the sensed operating condition whereby energizing the circulatory system causes the electrolyte solution to be circulated through the cells.

72. The method of claim 71 wherein the operating condition is temperature of the electrolyte solution.

73. A method of controlling a power generating system comprising a plurality of metal-air cells and a circulatory system for circulating an electrolyte solution through the cells, the circulatory system including a heat exchanger with a fan for forcing air over the heat exchanger to cool the electrolyte solution circulating in the heat exchanger, the method comprising energizing the cooling fan when the temperature of the electrolyte solution exceeds a predetermined temperature T_3 and de-energizing the cooling fan when the temperature of the electrolyte solution is less than a predetermined temperature T_2.

74. A method of controlling a power generating system during start-up of the system, the system comprising a plurality of metal-air cells and a circulatory system for circulating an electrolyte solution through the cells, the

cells being initially substantially empty of electrolyte solution, the method comprising the steps of

(a) turning the circulatory system on for a predetermined time t_1 and turning the circulatory system off for a predetermined time t_2;

(b) sensing the temperature of the electrolyte solution in at least one cell;

(c) repeating steps (a) and (b) until the sensed temperature of the electrolyte solution in the cell is at least T_1, and then sensing the temperature of the electrolyte solution in the circulatory system.

75. The method according to claim 74 further comprising the step of:

repeated steps (a)-(c) until the temperature of the electrolyte solution in the circulatory system is at least T_s, and then turning the circulatory system on to run continuously.

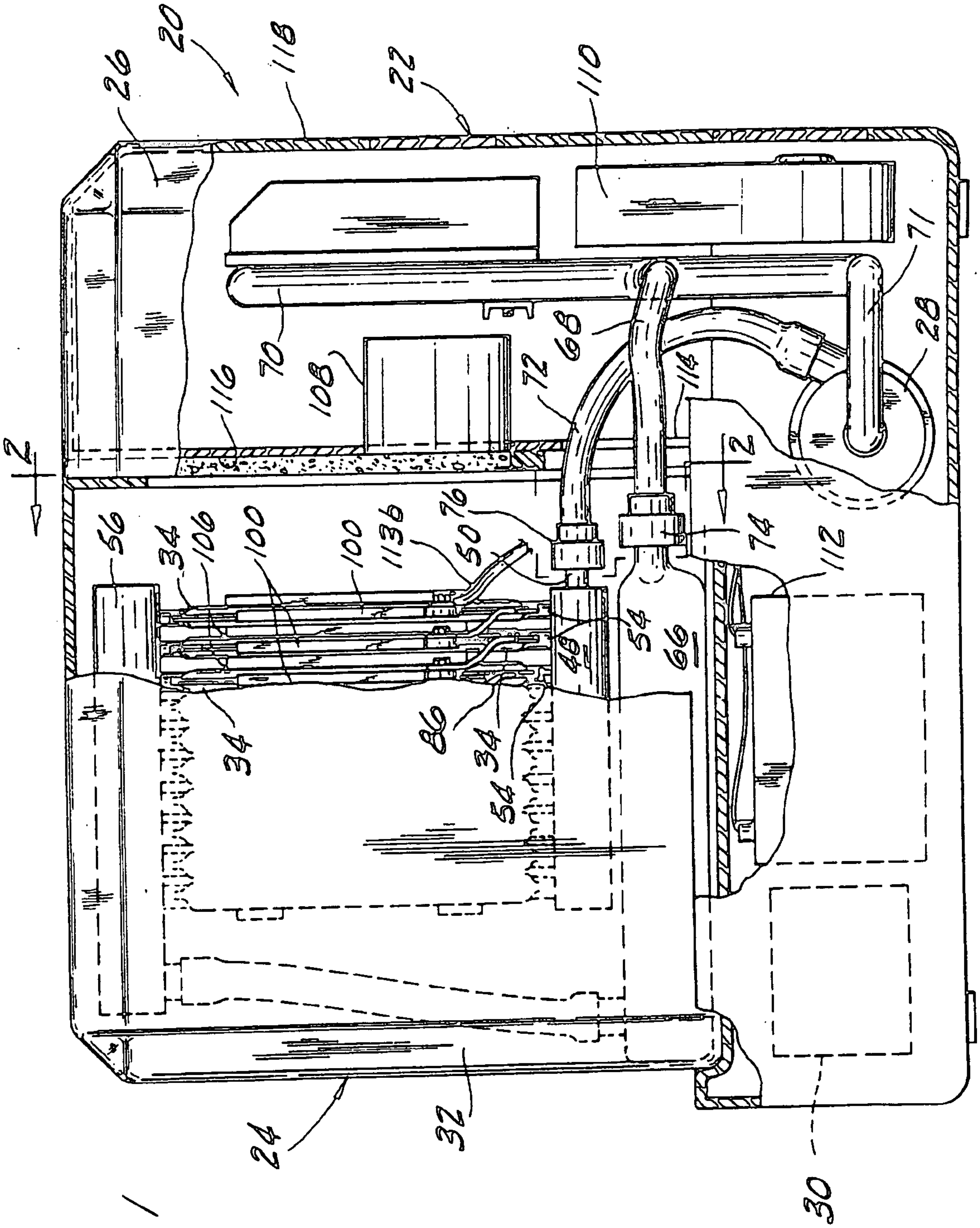
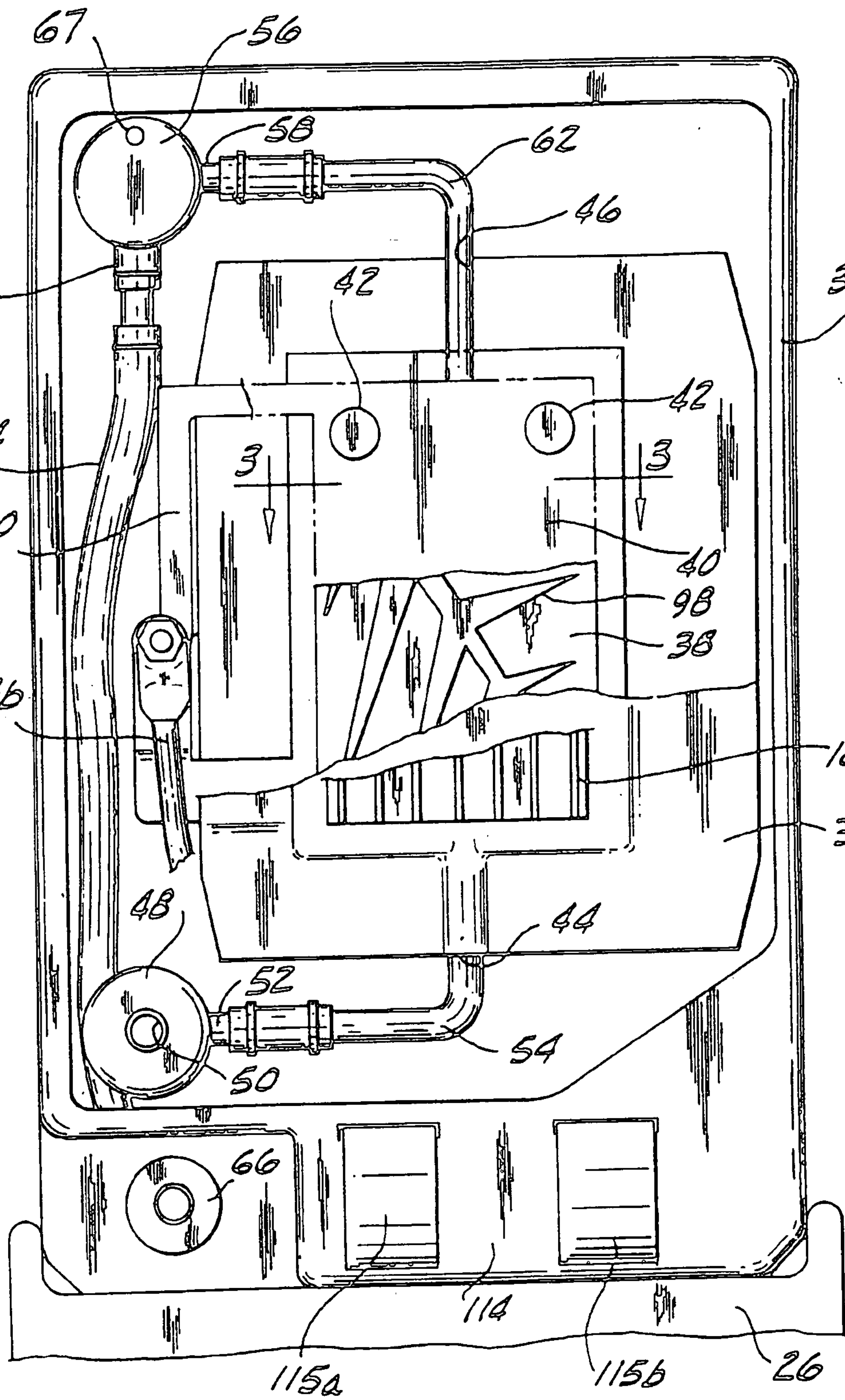


FIG. 1

FIG.2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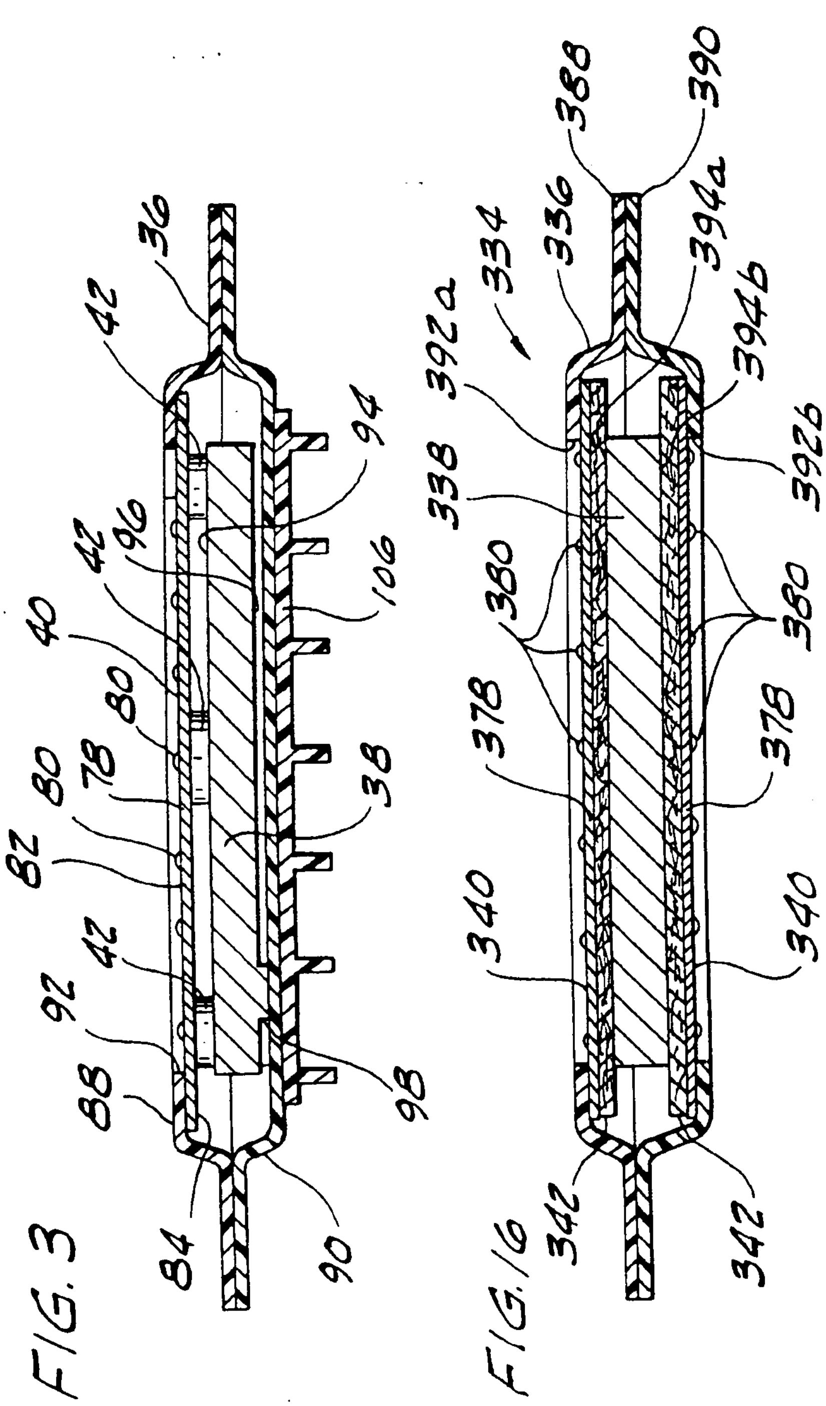
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336
394a
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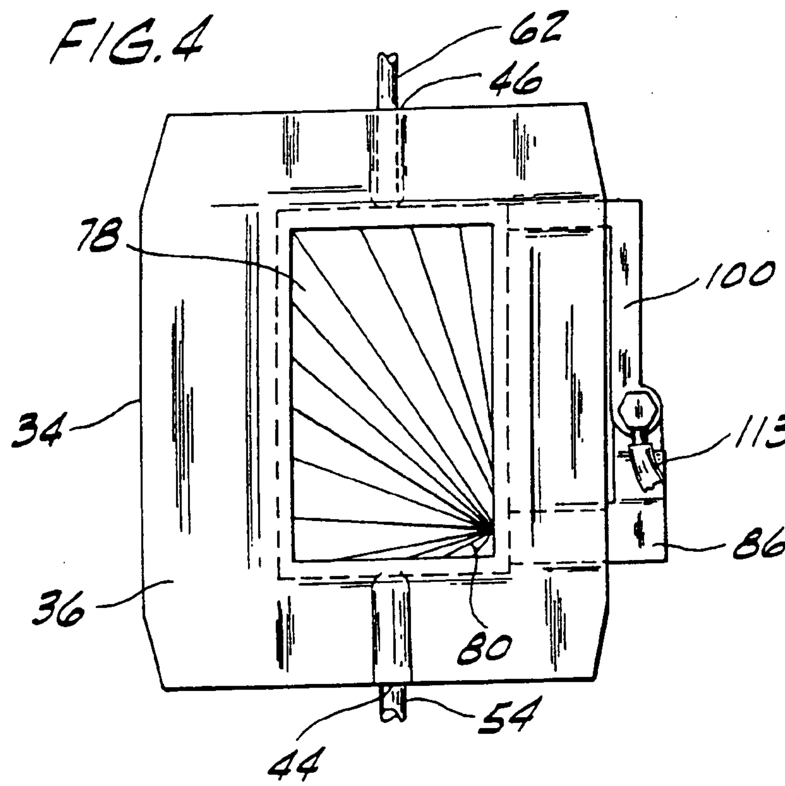
FIG. 3

FIG. 16

FIG.4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113b
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54
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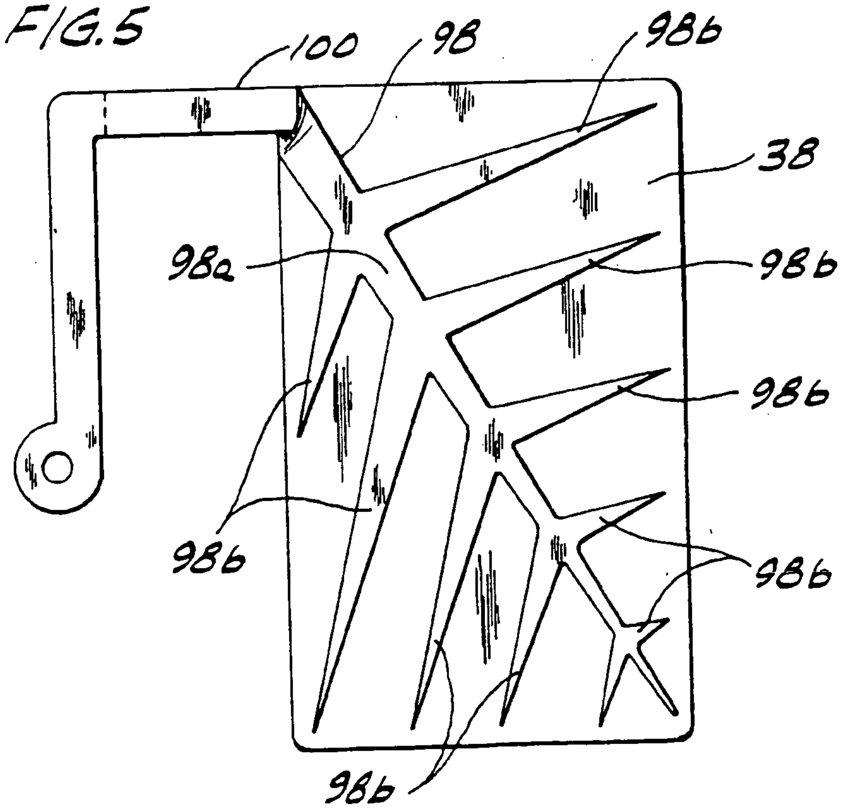
FIG.5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98a
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98b
98b

FIG. 6

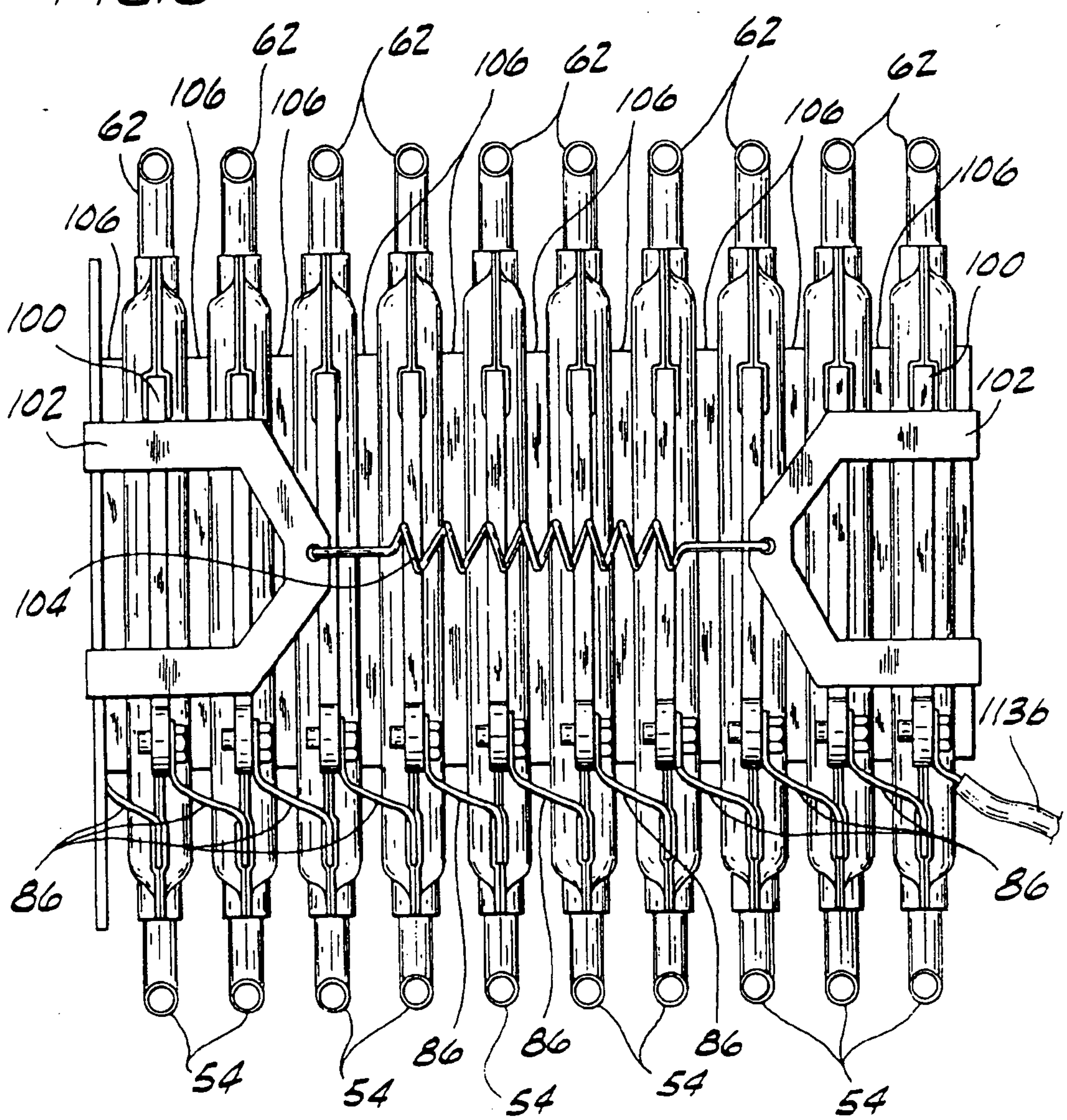
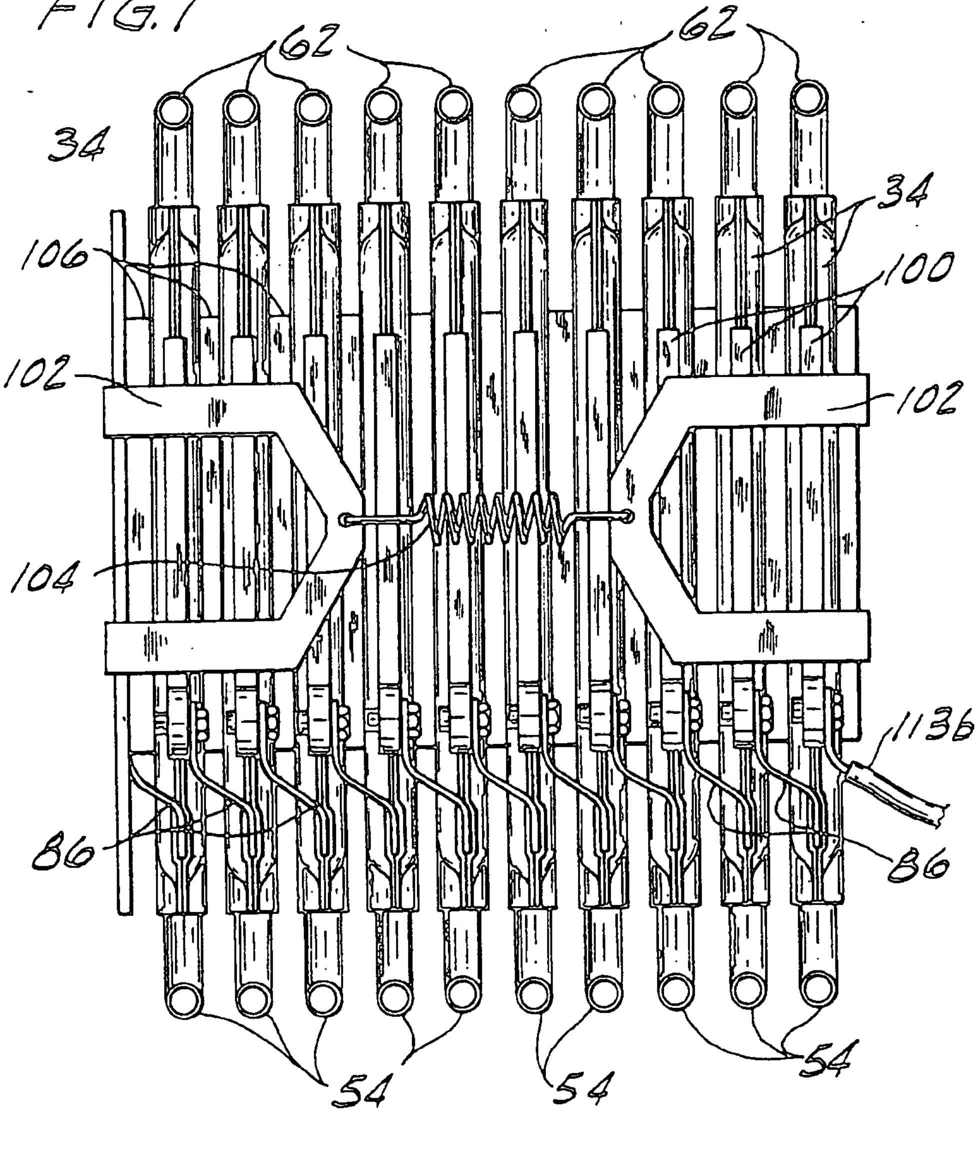
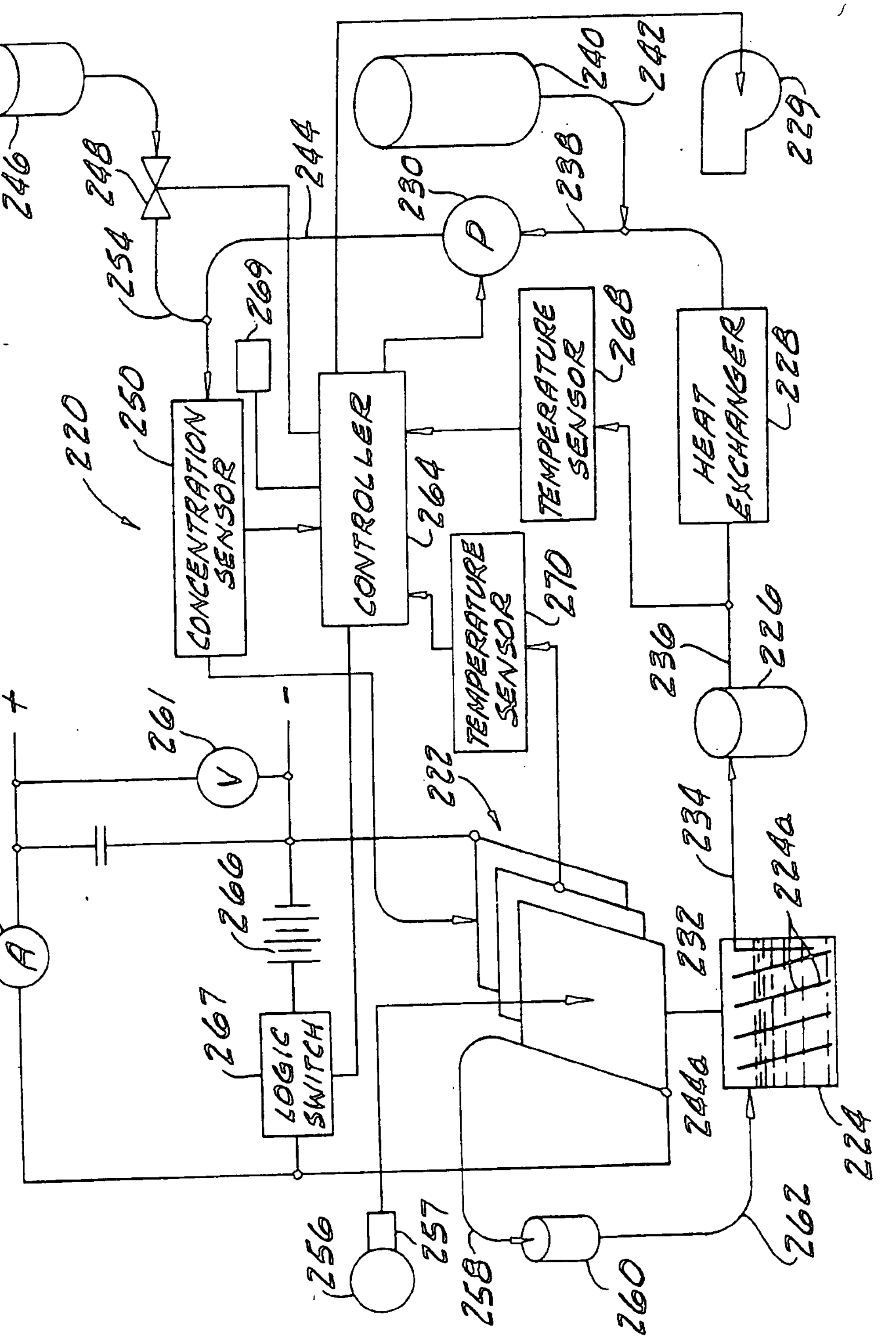


FIG.7

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CONCENTRATION SENSOR
CONTROLLER
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268
HEAT EXCHANGER
228
TEMPERATURE SENSOR
270
236
226
+
261
V
-
222
263
A
266
234
224a
232
267
LOGIC SWITCH
244a
224
262
256
257
258
260

FIG. 8

FIG. 9

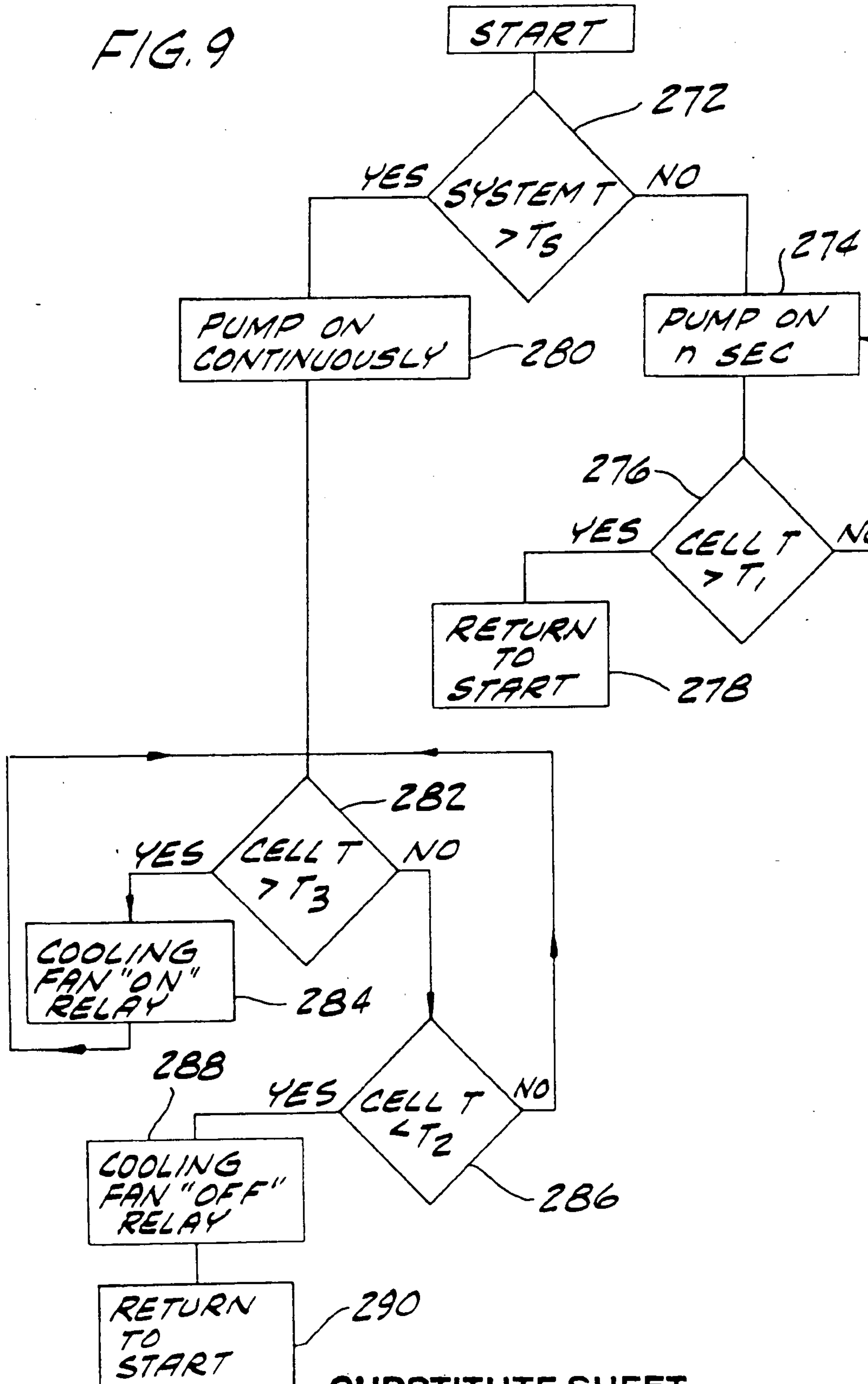

START
272
SYSTEM T
> T_S
YES
NO
274
PUMP ON
n SEC
PUMP ON
CONTINUOUSLY
280
276
CELL T
> T_1
YES
NO
RETURN
TO
START
278
282
CELL T
> T_3
YES
NO
COOLING
FAN "ON"
RELAY
284
288
CELL T
< T_2
YES
NO
286
COOLING
FAN "OFF"
RELAY
RETURN
TO
START
290

FIG. 10

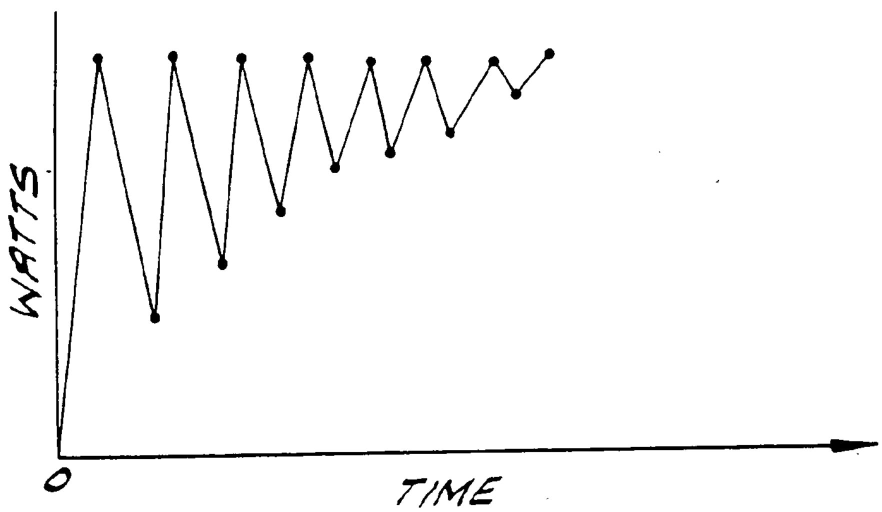

WATTS
0
TIME

FIG. 11

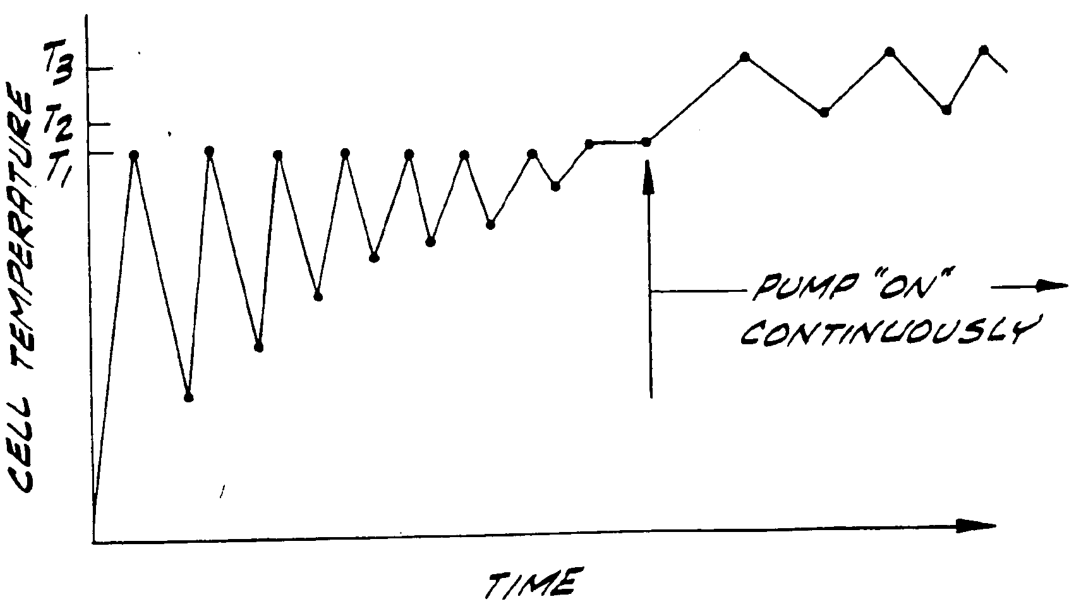

CELL TEMPERATURE
T3
T2
T1
PUMP "ON"
CONTINUOUSLY
TIME

FIG.12

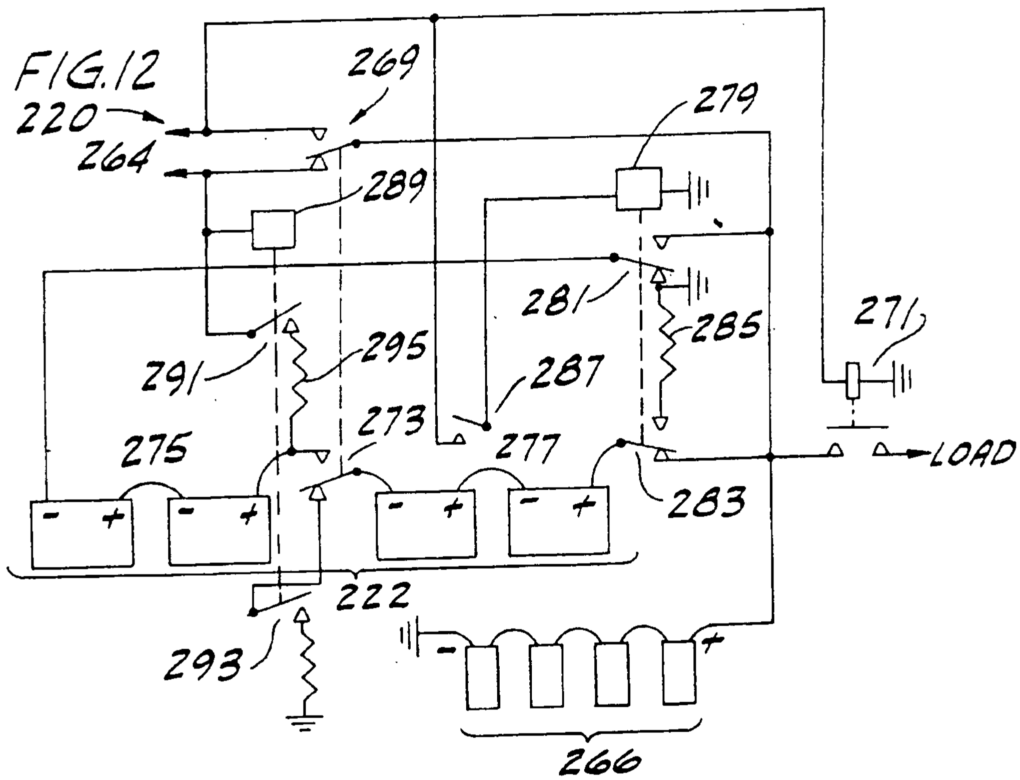

220
264
269
289
279
281
285
271
291
295
287
273
275
277
283
LOAD
222
293
266

FIG.13

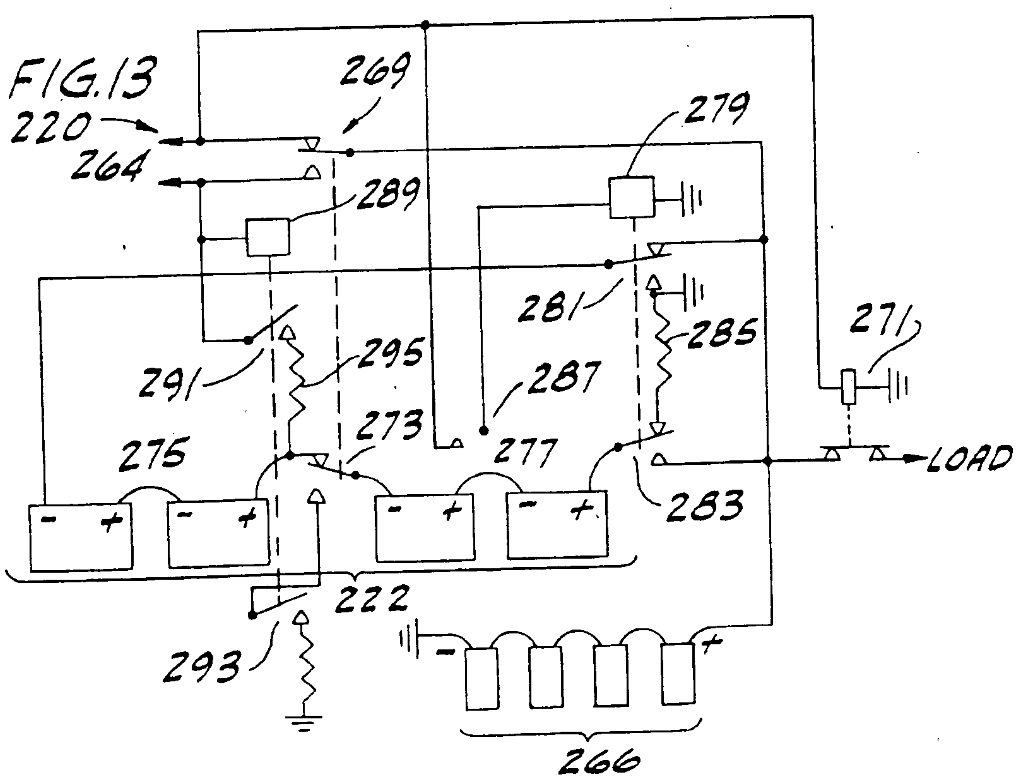

220
264
269
289
279
281
285
271
291
295
287
273
275
277
283
LOAD
222
293
266

FIG. 14

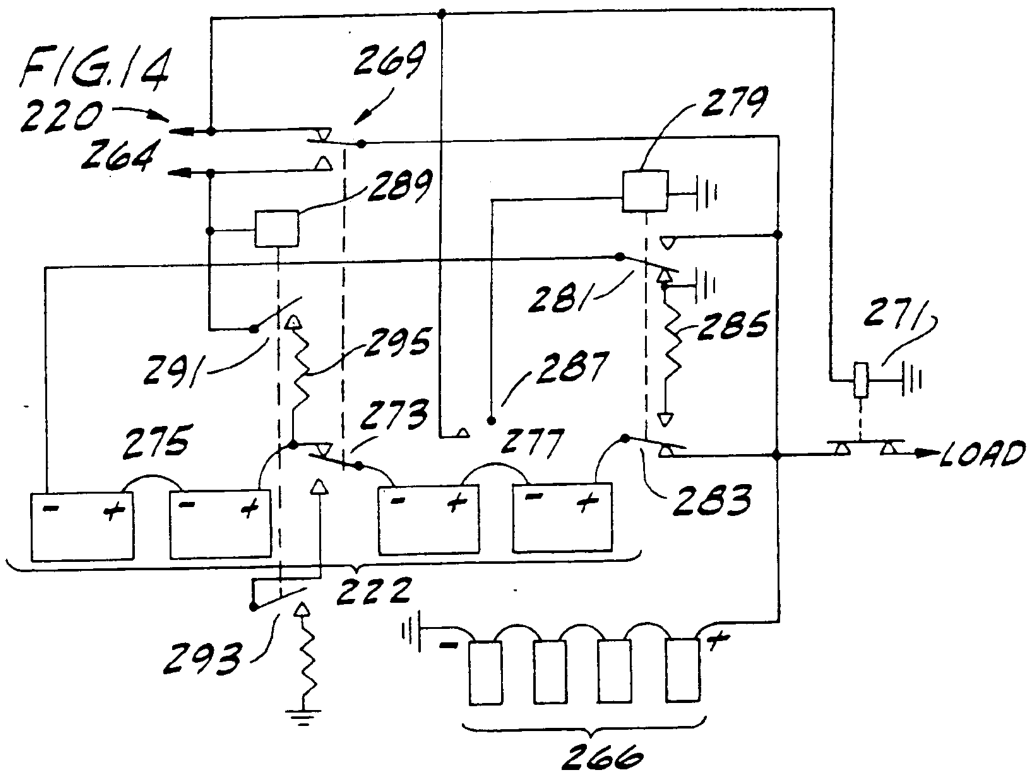
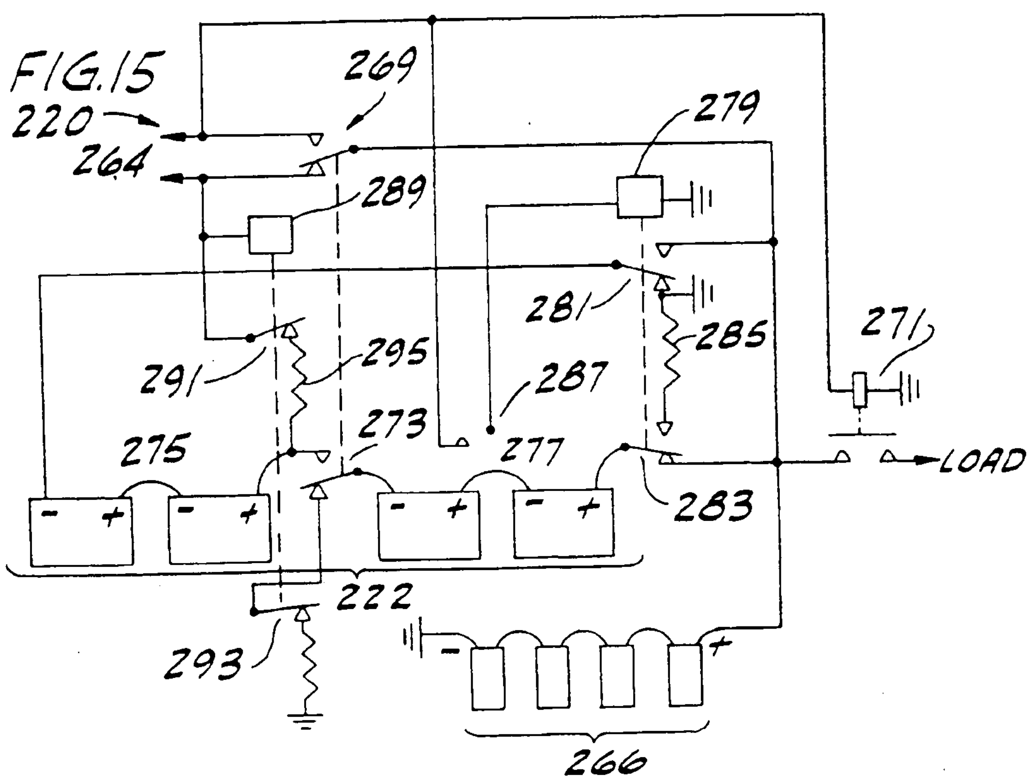

269
220
264
279
289
281
285
271
291
295
287
273
277
LOAD
275
283
222
293
266

FIG. 15


269
220
264
279
289
281
285
271
291
295
287
273
277
LOAD
275
283
222
293
266

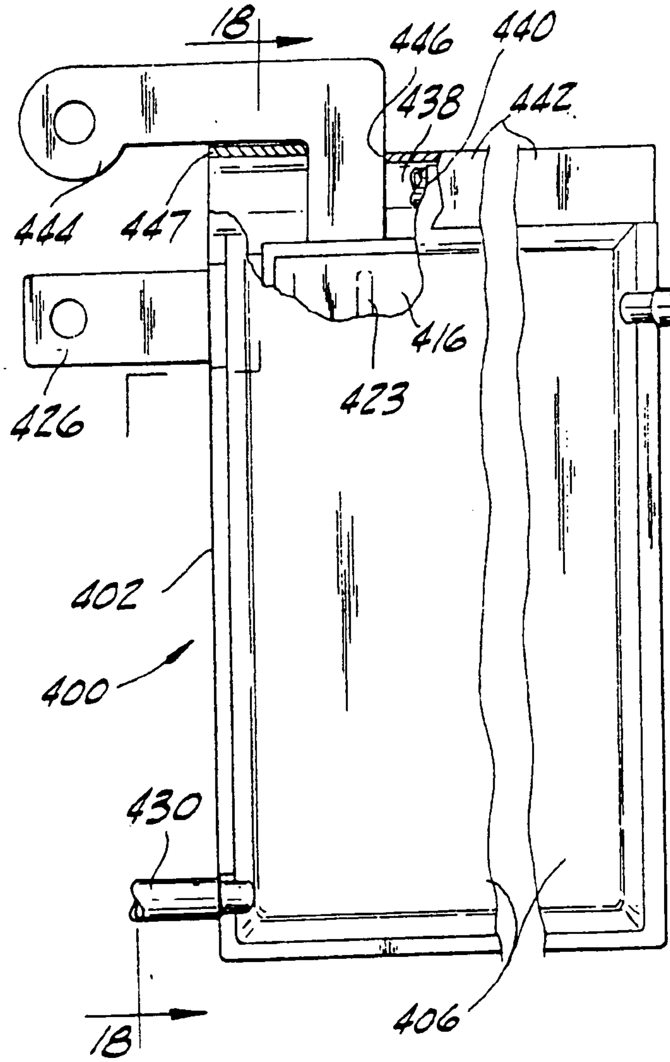


FIG.17

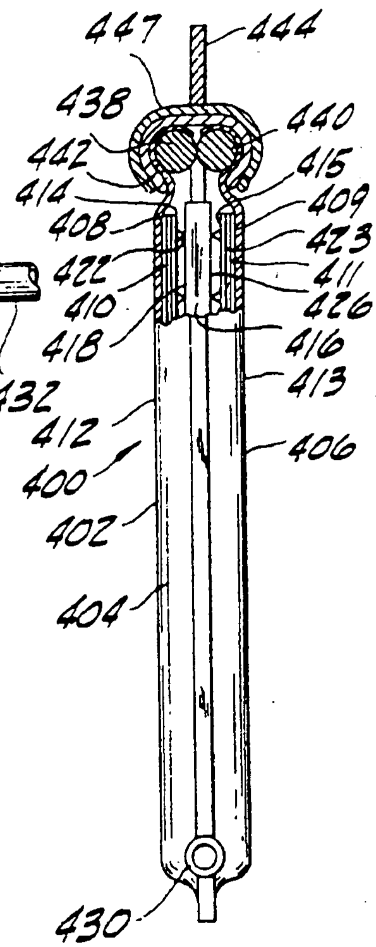


FIG.18

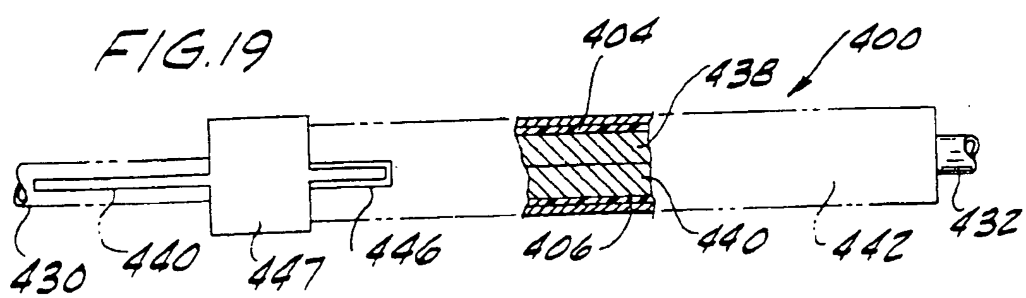


FIG.19

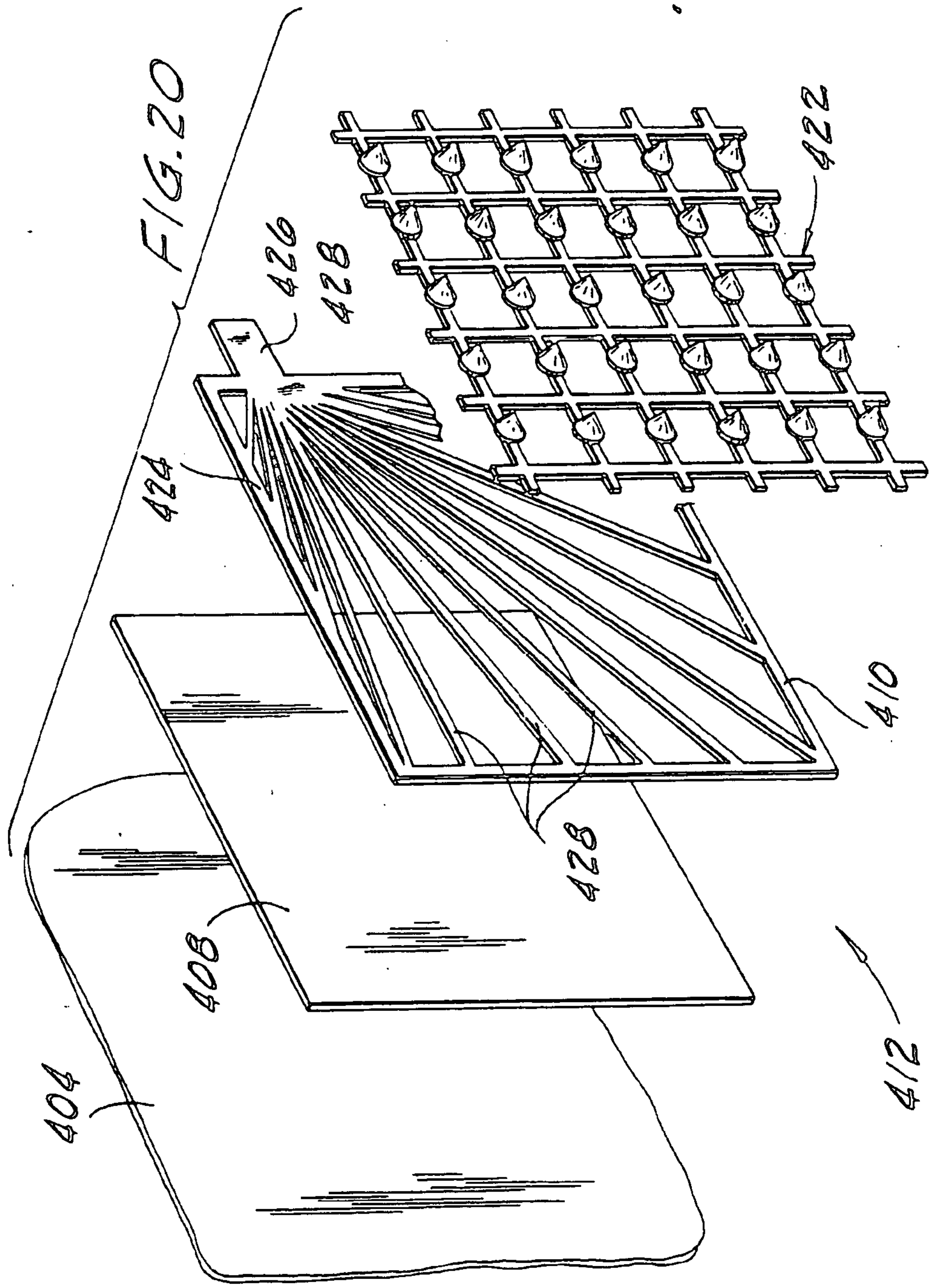


FIG. 20

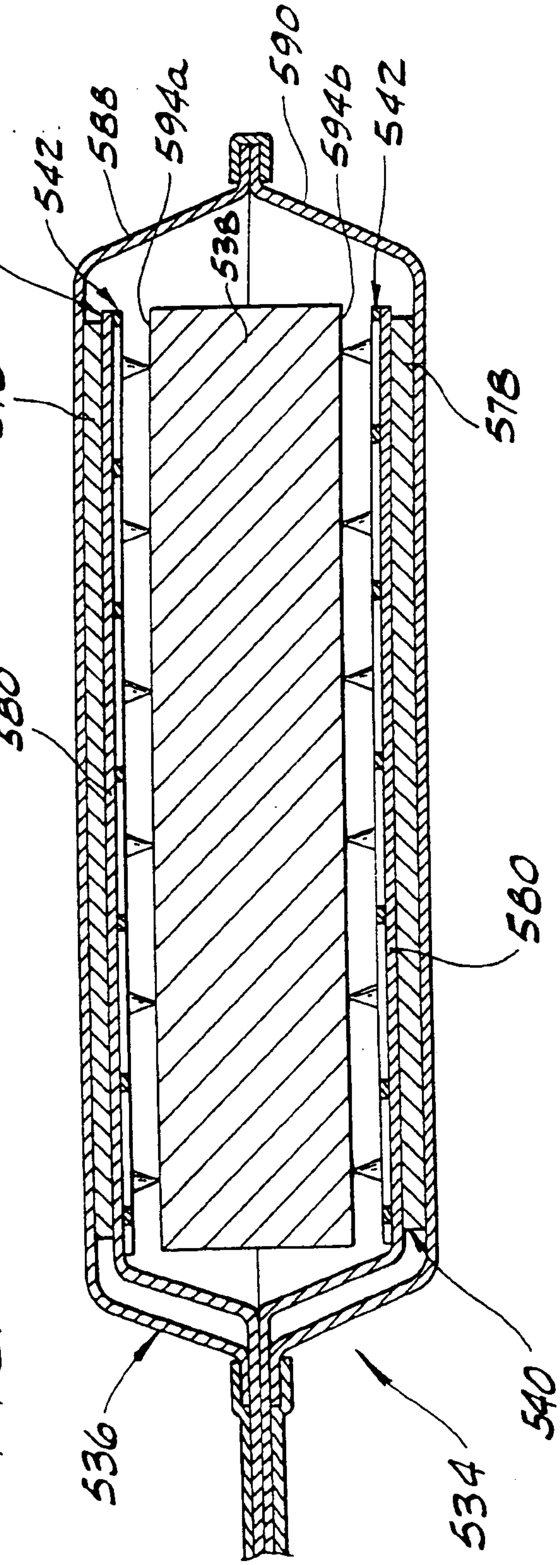


FIG.21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/09188

A. CLASSIFICATION OF SUBJECT MATTER
IPC(5) :H01M 8/02, 8/04, 8/08, 8/24
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/12, 13, 14, 18, 22, 23, 24, 25, 26, 27, 28, 34, 35, 36, 37, 38, 50, 51, 52, 61, 62, 63, 72, 81, 112, 122, 129, 130, 139, 146, 152

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	New Scientist, issued 17 July 1986, Fitzpatrick et al., "Aluminium is a fuel for tomorrow", pages 34-37, entire document.	1-75
Y	Chemistry and Industry, issued 17 March 1986, G. Scamans, "Advances in battery technology: Development of the aluminium/air battery", 4 pages - unnumbered, entire document.	1-75
Y	Lawrence Livermore National Laboratory, UCRL-89155 preprint, issued 10 May 1983, Cooper et al., "Current Status of the Development of the Refuelable Aluminum-air Battery", pages 1-7, entire document.	1-75

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be part of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier document published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search 26 January 1994	Date of mailing of the international search report 07 FEB 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer MICHAEL B. HYDORN Telephone No. (703) 308-1236

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/09188

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ALUPOWER, INC., issued June-July 1992, Alupower, Inc., "HIGH ENERGY DENSITY: Disposable Aluminum-air Battery, pages 1-7, entire document.	1-75
Y	Lawerence Livermore Laboratory, UCRL-53536, issued December 1984, J.F. Cooper, "Aluminum-air Power Cell Research and Development Progress Report", pages 1-17, entire document.	1-75
Y	US, A, 3,650,839 (Lang et al.) 21 March 1972, entire document.	1-75

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/09188

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
(Form PCT/ISA/206 Previously Mailed.)
Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☒ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

429/12, 13, 14, 18, 22, 23, 24, 25, 26, 27, 28, 34, 35, 36, 37, 38, 50, 51, 52, 61, 62, 63, 72, 81, 112, 122, 129, 130, 139, 146, 152

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

I. Claims 1-5, 9-25 & 37-45, drawn to metal-air cells having a flexible, collapsible pouch; classified in Class 429, and a plurality of subclasses, such as 22 and 27.

II. Claims 6-8, 26-36 & 46-54, drawn to batteries comprising a stack of metal-air cells having a flexible, collapsible pouch; classified in Class 429, and a plurality of subclasses, such as 22 and 27.

III. Claims 55-70, drawn to batteries comprising a stack of metal-air cells; classified in Class 429, and a plurality of subclasses, such as 22 and 24.

IV. Claims 71-75, drawn to methods of controlling a power system comprising a stack of metal-air cells, classified in Class 429, subclass 13.

PCT Rule 13.1 states that the international application shall relate to one invention only or to a group of inventions so linked as to form a single general inventive concept ("requirement of unity of invention").

PCT Rule 13.2 states that unity of invention referred to in Rule 13.1 shall be fulfilled only when there is a technical relationship among those inventions involving one or more of the same or corresponding special technical features.

Annex B, Part 1(a), indicates that the application should relate to only one invention, or if there is more than one invention, inclusion is permitted if they are so linked to form a single general inventive concept.

Annex B, Part 1(b), indicates that "special technical features" means those technical features which as a whole define a contribution over the prior art.

Annex B, Part 1(c), further defines independent and dependent claims. Unity of invention only is concerned in relation to independent claims. Dependent claims are defined as a claim which contains all the features of another claim and is in the same category as the other claim. The category of a claim refers to the classification of claims according to subject matter, e.g. product, process, use, apparatus, means, etc.

Annex B, part 1(e), indicates the permissible combinations of different categories of claims. Part 1(e(ii)) states that inclusion of an independent claim for a given process, an independent claim for an apparatus or a means specifically designed for operating said process is permissible.

Herein Group I is distinct from Groups II-IV, Group II is distinct from Groups I & III-IV, Group III is distinct from Groups I-II & IV, and Group IV is distinct from Groups I-III, because, as claimed, the elements required in Groups I-III are not co-mutual: that is Group I is directed toward a single metal air cell; Group II is directed toward the distinct stacked metal air cell batteries; Group III does not possess the flexible, collapsible pouch of Group II and are therefore distinct stacked metal air cell batteries; and Group IV is a distinct process because it controls the stacked metal air cells, not that the apparatus is specifically designed for operating said process. Thus each group is independent of each other.